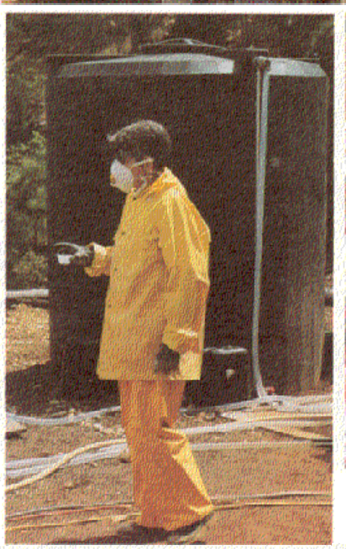
United States Environmental Protection Agency

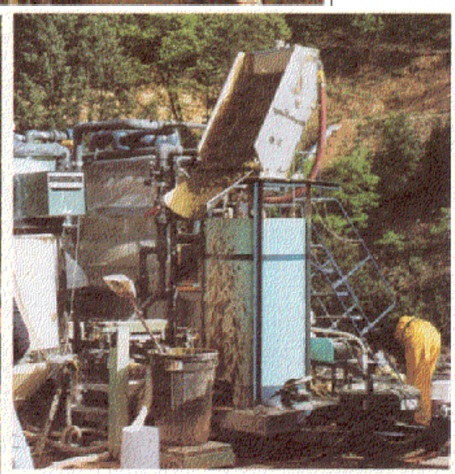
Office of Research and Development
Washington DC 20460

EPA/540/AR-93/513
September **1995**

EPOC Water Inc. Microfiltration Technology

Applications Analysis Report





SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

EPA/540/AR-93/513
September 1995

EPOC Water Inc. Microfiltration Technology

Applications Analysis Report

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency under Contract No. 68-CO-0048 and the Superfund Innovative Technology Evaluation (SITE) Program. It has been subjected to the Agency's peer review and administrative review, and it has been approved for publication as a U.S. EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems ; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

This document is an evaluation of the performance of the EPOC Water, Inc. Microfiltration Technology and its applicability as a treatment technique for water contaminated with metals. Both the technical aspects and the economics of this technology were examined. Operational data and extensive sampling and analysis information were carefully compiled to establish a data base against which the vendor's claims for the technology have been compared and evaluated. Other information provided by the vendor, and summarized in this report, was also taken into account in this evaluation. Conclusions concerning the technology's suitability for use in removing metals from acid mine drainage were reached, and extrapolations regarding applicability to other sites with different contaminants and liquid wastes are also provided.

EPOC's system consisted of a reaction (precipitation) chamber, microfiltration units, dewatering units, and auxiliary equipment. The microfiltration unit (EXXFLOW) utilizes a unique fabric support operating with a formed-in-place dynamic membrane. The system also includes a pressurized tubular fabric dewatering unit, the EXXPRESS, which operates on the same.microfiltration principles. According to the vendor, particulates 0.1 μm in diameter or larger are removed by the EXXFLOW and the concentrate (reject) slurry can be dewatered in the EXXPRESS. Dissolved metals present in acid mine drainage water or other contaminated waters first must be precipitated by chemical treatment to enable removal by filtration.

The EPOC Microfiltration Technology was demonstrated under the U.S. EPA SITE program at the Iron Mountain Mine Superfund site near Redding, California in May and June of 1992. The water source for most of this demonstration, acid mine drainage from the Old No. 8 Mine Seep, contained about 3,000 mg/L of total metals, primarily aluminum and iron, with much smaller concentrations of heavy metals. Chemical precipitation with various alkalies and recirculation through the EXXFLOW microfiltration unit increased the suspended solids in the concentrate to about 10,000 to 35,000 mg/L. Further concentration and dewatering with the EXXPRESS achieved 12% to ~ 30% solids in the filter cakes, rather than the claimed 20% to 40 % , depending on the alkali used for precipitation. Considerable operating difficulty was encountered with the EXXPRESS unit as configured for the demonstration. The filter cakes all passed the TCLP.

The permeate from the ON8 seep using the EXXFLOW was of high quality. The metals were successfully removed, meeting all claims with the exception of aluminum and, occasionally, manganese and iron. Where elevated concentrations of heavy metals were present (e.g., copper at 170 mg/L), these were consistently reduced to less than 0.1 mg/L (e.g., copper in permeate: <0.05 mg/L). The permeate turbidity was consistently less than 1 NTU in all cases. The permeate pH was usually in the 9 to 10 range and would probably require acidification before it could be discharged.

The estimated cost for a 1-yr remediation using two sizes of the EPOC EXXFLOW system was $125.00/1000 gal **($33.50/m^3)** for the 7 gpm (26.5 L/min) pilot-scale unit with no dewatering of the concentrate, $103/1000 gal **($27.25/m^3)** with conventional dewatering and $47.40/1000 gal **($12.50/m^3)** for the 50 gpm (190 **L/min**) full-scale system with dewatering. The EXXPRESS unit was not used in the cost analysis.

This demonstration was conducted for the Risk Reduction Engineering Laboratory (now the National Risk Management Research Laboratory) in April-July 1992, and work was completed as of September 1993.

Contents

Contents (continued)

Tables

Figures

Abbreviations and Symbols

AMD	Acid Mine Drainage
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of I980
gpd	gallons per day
gpm	gallons per minute
HSWA	Hazardous and Solid Waste Amendments to RCRA - 1984
kWh	kilowatt-hour
mg/L	milligrams per liter
NPDES	National Pollutant Discharge Elimination System
PEL	Permissible Exposure Limit
NTU	Nephelometric Turbidity Units
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration or Act
OSWER	Office of Solid Waste and Emergency Response
NPL	National Priorities List
POTW	publicly owned treatment works
ppb	parts per biiion (µg/l)
ppm	parts per million (mg/L)
psi	pounds per square inch pressure
psig	pounds per square inch, gauge pressure
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act of 1976
RREL	Risk Reduction Engineering Laboratory
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act of 1986
scfm	standard cubic feet per minute
SITE	Superfund Innovative Technology Evaluation
TCLP	Toxicity Characteristic Leaching Procedure
TSD	Treatment, Storage, and Disposal
VOC	Volatile Organic Chemical

Conversion Factors

	English (US)	x Factor	= Metric
Area:	1 ft^2	x 9.29×10^{-2}	= m^2
	1 in'	x 6.45	= cm^2
Flow Rate:	1 cfm	x 2.83×10^{-2}	= m^3/min
	1 gal/min	x 6.31×10^{-5}	= m^3/s
	1 gal/min	x 6.31×10^{-2}	= L/s
	1 Mgal/d	x 43.81	= L/s
	1 Mgal/d	x 3.78 x 10	= m^3/d
	1 Mgal/d	x 4.38×10^{-2}	= m^3/s
Length:	1 ft	x 0.30	= m
	1 in	x 2.54	= cm
	1 yd	x 0.91	=m
Mass:	1 lb	x 4.54×10^{2}	= g
	1 lb.	x 0.454	= kg
Volume:	1 ft^3	x 28.31	=L
	1 ft^3	x 2.83×10^{-2}	= m^3
	1 gal	x 3.78	= L
	1 gai	x 3.78×10^{-3}	= m^3
Pressure:	1 psia	x 51.71	= cm Hg

ft = foot, ft^2 = square foot, ft^3 = cubic foot
in = inch, in^2 = square inch
yd=yard
lb = pound
gal = gallon
gal/min (of gpm) = gallons per minute
Mgal/d (or MGD) = million gallons per day
m = meter, m^2 = square meter, m3 = cubic meter
cm = centimeter, cm^2 = square centimeter
L = liter
g=gram
kg = kilogram
cfm = cubic feet per minute
L/s = liters/sec
m^3/d = cubic meters per day

Acknowledgments

This report was prepared under the direction and coordination of Mr. Jack Hubbard, EPA Superfund Innovative Technology Evaluation (SITE) Project Manager in the National Risk Management Research Laboratory (formerly the Risk Reduction Engineering Laboratory), Cincinnati, Ohio. Contributing authors were: Mr. Robert Dvorin, Mr. Dan Patel, Mr. Ray Martrano. Ms. Linda Hunter and Ms. Ruth Alfasso of SAIC.

This report was prepared for EPA's SITE Program by the Environmental Technology Division of Science Applications International Corporation (SAIC) under U.S. EPA Contract No. 68-CO-0048.

Section 1

Executive Summary

1.1 Introduction

The *EPOC* **microfitration technology, using** a dynamic (formed-in-place) membrane to remove, concentrate. and dewater suspended solids (down to 0.1 micrometer, µm, diameter), was evaluated on acid mine drainage (AMD) at the Iron Mountain Mine Super-fund site near Redding, California. Operating and cost data collected from this demonstration provide the basis for this evaluation.

Microfiltration allows for removal of very small particles of suspended solids (to 0.1 um). A dynamic membrane, which is constantly renewed, is expected to be more resistant to plugging and fouling, thereby requiring less downtime far cleaning. The EPOC system used a patented design of woven textile tubes as the support for the dynamic membranes.

The dissolved metals in the acid mine drainage were precipitated with various alkalies in a mechanically mixed reaction tank physically separated and concentrated in the EPOC EXXFLOW microfiltration unit, and dewatered in the EPOC EXXPRESS system. The final products of this process are the decontaminated water and a small volume of filter cake containing the contaminants.

This report offers information useful in assessing the suitability of this process to other similar sites, and includes additional information (supplied by the developer) relative to performance on other types of contaminated water.

The primary objectives of this demonstration were to:

- Assess the ability of the EPOC microfiltration technology to remove metals present in the acid mine drainage (AMD) at the Iron Mountain Mine site, using various precipitating chemicals;
- Evaluate the technology's capability to dewater the metals-bearing sludge formed as result of the treatment of the AMD wastewater.
- Assess **the** quality of the treated water and the dewatered metals-bearing sludge thus produced, and
- Develop capital and operating costs for the EPOC microfiltration technology.

1.2 Conclusions

The results and observations of the SITE demonstration at Iron Mountain Mine provide the bases for the following conclusions:

A. When operated at a rate of about 11 L/min (3 gpm) on acid mine drain water containing about 3000 mg/L of total metals:

- The EXXFLOW microfiltration system met the developer's claims for removal of heavy metals in the AMD but did not meet the claim for aluminum (1 mg/L) with all alkalies used as the precipitating chemical.
- The EPOC microfiltration system reduced cadmium, copper, and zinc in the permeate to <50 ppb each.
- Aluminum was reduced to less than 1 mg/L when magnesium oxide (Mg0) was used; hydrated lime ($Ca(OH)_2$) or caustic soda (NaOH) produced residual concentrations of about 15-50 mg/L of aluminum.
- Flow rate, pressure, and a flux of about 2650 $L/m^2 \cdot day$ (65 $gal/ft^2 \cdot day$) were essentially constant for the duration of each demonstration run (4 to 6 hr), indicating that the EXXFLOW unit should operate for extended times with minimal maintenance and cleaning.
- The EXXPRESS dewatering unit experienced serious operating problems that required operator attention and prevented effective evaluation.

- Dewatered filter cake volume was less than 5% of the treated water volume in all runs (i.e., water recovery as permeate was 95% or better).

- None of the filter cakes met the developer's claims for solids content. Caustic treatment produced a sludge cake with about 12% dry solids (claimed: >20%). Hydrated lime, magnesium oxide . or a combination of magnesium oxide and caustic soda treatment resulted in filter cakes containing about 30% dry solids (claimed: >40% with lime).

- The **dewatcred filter cakes, in all runs, passed the TCLP** (toxicity characteristic leaching procedure) test but were composed primarily of metals other than those analyzed in the test (e.g., Al, Fe).

- Based on the demonstration tests, other information, and the use of other dewatering approaches for the concentrate, the cost to treat metal contaminated wastes such as the ON8 acid mine drainage is estimated at \$125/1000 gal **(\$33/m^3)** with a 7 gpm (26.5 L/min) unit with disposal of the reject as a liquid waste and \$103/1000 gal **(\$27/m^3)** with dewateaing of the reject stream. For a 50 gpm (190 L/min) system, with dewatering of the reject, the estimated cost is \$47.40/1000 gal (\$ **12.50/m^3).** These costs are based on a 90% on-line factor, a total treatment time of twelve months, and 50% sodium hydroxide as the treatment chemical. The cost of caustic is a major cost factor.

B. When acid mine drainage containing about 20,000 mg/L of dissolved metals (primarily iron, aluminum, copper, and zinc) was treated at a rate of 3.8 L/min (1.0 gpm) with a combination of magnesium oxide and caustic soda:

- Residual metals in the permeate met the developer's claims except for iron (which was, nevertheless, reduced by 99.9%). cadmium, and manganese.

- Flux in the EXXFLOW unit was maintained at about 730 **L/m^2•day** (18 **gal/ft^2•day)** with a feed concentration of about 7% w/w suspended solids.

- Dewatered filter cake passed the TCLP test for metals. Dry solids in the dewatered filter cake, 26%, did not meet the 40% claim. Water recovery was 76%.

C. The EPOC system may have utility in removing metals and suspended solids from a wide variety of waste and process streams. The system requires minimal floor space and probably can surpass other clarification means where needed to meet discharge requirements. Metal-containing streams would be well-suited to the process, and, based on information provided by the developer, oil emulsions and other solids that do not settle readily may be good candidates.

1.3 Discussion of Conclusions

A trailer-mounted EPOC microfiltration system with a design flow rate of 26.5 L/min (7 gpm) but operated at 11 L/min (3 gpm) and 3.8 L/min (1 gpm) was tested at the Iron Mountain Mine Superfund site. Extensive data were collected ove r nine demonstration runs of 4 to 6 hr duration to assess (a) dissolved metals reduction, (b) sludge dewatering capabilities, (c) operational requirements, and (d) operating costs. Data generated by this testing serve as the basis for the preceding conclusions.

A Quality Assurance (QA) program was conducted by SAIC in conjunction with EPA's QA program which includes audits and data review as well as corrective action procedures. This program is the basis for the high quality of data obtained from the SITE project.

Extensive data were collected on the metals, acidity, alkalinity, pH, sulfate, and total solids of the water before and after treatment Suspended solids concentration of the feed to the microfilter was determined. The dewatered filter cake was analyze dfor moisture, density, pH, metals, and TCLP (toxicity characteristic leaching procedure) for metals.

The key factors affecting performance of the system were neutralizing chemical choice and chemical feed rate control. Caustic soda produced the most hydrated sludge cake, which is to be expected. Aluminum concentrations in the permeate remained higher than anticipated when either caustic or lime was used because it was difficult to control the pH and any excess alkali redissolved the amphoteric aluminum. Magnesium oxide, and a combination of magnesium oxide and caustic, allowed more precise control of pH and this was reflected in improved aluminum removal.

The EXXFLOW microfiltration unit operated effectively in producing a permeate with very little residual metals. With **the Old No.** 8 Mine Seep water, about 95% of the feed water could be recovered as permeate meeting all heavy metal objectives. With the Richmond Portal AMD containing significantly higher concentrations of aluminum, iron and other metals, permeate water accounted for 76% of the feed water. Although the several runs were shorter than planned. the absence of any gradual deterioration in flow rate, pressure, or flux suggests that the microfiltration unit would operate over a long time with minimal downtime for cleaning.

In addition to affecting the nature of the solids and the rate at which they are produced, the chemical agent apparently also affected the ease with which the sludge generated in the EXXFLOW microfiltration unit could be further dewatered in the EXXPRESS unit, The result was that sludge generated by caustic precipitation could only be dewatered to about 12% solids, while lime or magnesium oxide produced sludges that could be dewatered to 25% to 32% solids.

The EXXPRESS dewatering unit required frequent attention and manual cleaning, seemingly because the high concentration of metal hydroxides did not act hydraulically within the tubes as expected and the unit plugged. Almost constant operator attention was required on some runs. Either this device requires design modification to operate on heavy loads of metal hydroxide sludges, or it may be more suited for applications where the nature or quantity of solids is different.

Costs were estimated for two system sizes and assumed that approaches other than the EXXPRESS dewateaing unit are used to process the reject concentrate from the EXXFLOW. Direct disposal of the reject stream is more costly than dewatering. accounting for 36% of the pilot-plant costs. With dewatering, the cost for management of the reject decreased to 23%. In the full-scale system. dewatering accounts for 14.2% of the cost. Neutralizing chemical cost for a given volume of wastewater will remain essentially the same for any size of treatment system, but could change significantly with different wastewaters.

Section 2

Introduction

2.1 The SITE Program

In 1986. the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the Superfund Innovative Technology Evaluation (SITE) program to promote the development and use of innovative technologies to clean up Superfund sites across the country. SITE is helping to provide the treatment technologies necessary to implement new federal and state cleanup standards aimed at permanent remedies, rather than quick fixes. The SITE program is composed of four major elements: the Demonstration Program, the Emerging Technologies Program, the Measurement and Monitoring Technologies Program, and the Technology Transfer Program.

The major focus has been on the Demonstration Program. which is designed to provide engineering and cost data on selected technologies. EPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing. and evaluating all test results. The result is an assessment of the technology's performance, reliability, and cost. This information will be used in conjunction with other data to select the most technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. EPA will also accept proposals at any time when a developer has a treatment project scheduled with Super-fund waste. To qualify for the program, a new technology must be at the pilot- or full-scale stage and offer some advantage over existing technologies. Mobile and in situ technologies are of particular interest to EPA.

Once **EPA** has accepted a proposal. EPA and the developer work with the EPA Regional Offices and state agencies to identify a site containing wastes suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to evaluate the technology thoroughly and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the length of time and quantity of treated waste needed to assess the technology. After the completion of a technology demonstration, EPA prepares two reports. which are explained in more detail below. Ultimately. the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies could lead to the development of a system ready for field demonstration. The third component of the SITE program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative technologies to better characterize Superfund sites. The final component, the Technology Transfer Program. disseminates the information from all the studies to interested parties in the remediation community in the form of reports, bulletins, etc.

2.2 SITE Program Reports

The analysis of technologies evaluated in the Demonstration Program is contained in two documents: the Technology Evaluation Report and the Applications Analysis Report. The Technology Evaluation Report contains a comprehensive description of the demonstration sponsored by the SITE program and its results. It gives a detailed description of the technology, the site and waste used for the demonstration, sampling and analysis during the test. the data generated, and the quality assurance program.

The scope of the Applications Analysis Report is broader and encompasses estimation of other Superfund and hazardous waste site applications and costs of a technology based on all available data This report summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology as they may pertain to other sites with different characteristics.

Costs of the technology for different applications are estimated in the Applications Analysis Report, based on available data on pilot- and full-scale applications. The report discusses factors such as site and waste charactaistics that have a major impact on costs and performance.

The amount of available data for the evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic waste, or may include performance data on actual wastes treated at the pilot- or full-scale. Nevertheless, there are limits to conclusions regarding Superfund applications that can be drawn from a single field demonstration. A successful field demonstration does not necessarily assure that a technology will be widely applicable or fully developed to the commercial scale. The Applications Analysis Report attempts to synthesize whatever information is available and draw reasonable conclusions. This document will be very useful to those considering the technology for Superfund cleanups and represents a critical step in the development and commercialization of the treatment technology.

2.3 Key Contacts

For more information on the demonstration of the EPOC Microfiltration technology, please contact:

1. ERA Technical Project Manager concerning the SITE demonstration:

   S. Jackson Hubbard
   U.S. ERA Risk Reduction Laboratory
   26 West Martin Luther King Drive
   Cincinnati, OH 45268
   (5 13) 569-7507

2. Vendor concerning the process:

   Scott Jackson
   EPOC Water, Inc.
   3065 sunnyside. #101
   Fresno. CA 93727
   (209) 291-8144

3. For further information concerning The Iron Mountain Test site:

   Rick Sugarek
   Remedial Project Manager
   U.S. Environmental Protection Agency
   75 Hawthorne Street
   San Francisco, CA 94105
   (4 15) 744-2226

Section 3

Technology Applications Analysis

3.1 Introduction

This section of the report addresses the applicability of the EPOC Microfiltration process to waste streams that contain dissolved solids which can be precipitated and removed from the aqueous phase . This discussion is based upon information gathered from the SITE demonstration tests conducted at Iron Mountain Mine in Redding . CA and other information provided by the vendor. The demonstration tests provided a data base on which this process can be judged as to its applicability to this type of waste at other sites, Additional information for application of the EPOC microfiltration process at other sites, and with other wastes, is presented in Appendix D. The Technology Evaluation Report, a separate EPA document, provides an in-depth discussion of this SITE demonstration test and the analytical results.

The EPOC Microfiltration process is based on the ability of a semi-permeable membrane to retain suspended particulates while allowing the water and dissolved species to pass through the membrane. Microfiltration processes typically remove particles in the **0.1µm** to **1.0µm** range. EPOC's technology consists of a patented crossflow microfiltration module using dynamic membrane technology to achieve filtration separations for particles in the range of **0.1µm** to **0.2µm** with minimal fouling of the membrane and, consequently, minimal decrease in flux [throughput] over time. Suspended solids in the feed water deposit on the inner surface of porous tubes in the microfiltration module to form the dynamic membrane, and it is this membrane that controls the filtration process. Dissolved solids, e.g., metal ions, are chemically reacted to form particles which can then be filtered from the host liquid.

3.2 Conclusions

The following are overall conclusions from the evaluation of the EPOC Microfiltration process. The "Technology Evaluation" subsection discusses the data generated from the demonstration test in support of these conclusions.

- Dissolved heavy metals can be successfully removed from the water stream by the microfiltration process (EXXFLOW) when precipitated with any of several alkalies.

- The system generally met the vendor's claim for reduction of heavy metals in the permeate to 4.1 mg/L, but did not consistently meet claims for aluminum and iron reduction to **<1** mg/L. High concentrations of these two metals in the AMD feed waters and high alkalinity in the treated water may have been contributing factors. It must be noted, however, that some heavy metal concentrations in the feed water were below the claimed final concentrations.

- The performance of the EXXFLOW microfiltration system and the quality of the product water are dependent on the choice of base used for precipitation.

- The quantity and quality of the filter cake is a function of the base used. The filter cakes from the EXXPRESS dewatering system did not meet the vendor's claims of >20% solids (from caustic) and >40% solids (from lime).

- The system can produce filter cake from these AMD waters that wilI pass the TCLP requirement. recognizing that aluminum and iron were the major constituents in the sludge.

- The EXXPRESS dewatering unit required considerable attention and did not operate effectively as configured by the vendor for the demonstration.

Each waste stream to be treated by the process requires detailed characterization and selection of treatment chemicals and additives in order to develop optimal operating parameters.

The cost for treatment with the EXXFLOW process has been estimated at about $103/1000 gal with a 26.5 L/min (7 gpm) unit such as the pilot-plant system tested and decreases to about $47/1000 gal for a 190 L/min (50 gpm) unit, both coupled with dewatering of the reject. Chemical cost is a major factor with both units, but decreases significantly on scale-up. These costs were developed with a conventional filter press for dewatering because the EXXPRESS unit could not be operated effectively during the demonstration.

- It was not possible to determine the long term utility or reliability of the system since run lengths were limited to about 4 to 6 hours. However, there was little change in flux over the course of the tests, suggesting that extended operation of the EXXFLOW unit was feasible.

- Adjustment of the product water pH may be required before discharge, depending upon regulatory requirements.

- The process can be designed as a transportable unit or a permanent installation. For given sizes of EXXFLOW/EXXPRESS units, a reasonably wide range of process flow rates can be accommodated.

- **The** process **requires** a limited amount of site preparation before installation, including electric power and a level area for the unit. Units then can be placed in operation after a 1 to 2 week shakedown period.

3.3 *Technology Evaluation*

The following provides a more detailed discussion of the chemical and operational test results that were used to develop the foregoing conclusions. A summary of the test and analytical data is presented in Appendix C. Information on other applications of this technology along with performance data is presented in "Appendix D Case Studies". The estimated cost to treat waste streams is presented in detail in Section 4. "Economic Analysis'.

3.3.1 Chemical Test Results

The EPOC Microfiltration technology is designed to remove suspended solids from liquid wastes. Dissolved contaminants must first be converted to particulates (of appropriate size) using conventional technologies. Dissolved metals. which were the focus of this SITE demonstration test, can be treated with lime, caustic or magnesium oxide to precipitate the metals by forming insoluble metal hydroxides (and/or carbonates). The contaminant metals can then be removed from the water stream by filtration such as the EPOC microfiltration system. Other species, such as oils, can be coagulated or aggregated with or on coagulants and polyelectrolytes.

The SITE demonstration test was conducted at Iron Mountain Mine, Redding, CA. This site is contaminated with several acid mine drainage water sources that contain heavy metals. Two water sources were tested during the demonstration, Old No. 8 Mine Seep and Richmond Portal. Both waste streams are contaminated with high levels of iron, aluminum, copper and zinc. Several other metals were present at much lower levels, but were still considered critical in the evaluation of this technology.

Eight test runs were performed on water collected from the Old No. 8 Seep using caustic. lime, magnesium oxide, and a combination of caustic and magnesium oxide as the precipitating base. A combination of caustic and magnesium oxide also was evaluated on water from the Richmond Portal seep. One to three hours were required to reach andmaintain the desired pH (over 9) in the reaction tank before operation of the EXXFLOW unit was initiated Completed test runs averaged 4 to 5 hours during which grab and composite samples were collected of the raw feed, permeate, and filter cake. These samples were analyzed for metals to determine removal efficiencies. Other parameters were also measured to evaluate, for example, solids content of the filter cakes.

Caustic soda or lime treatment resulted in metals concentration well below the developer's claims, except for aluminum (and manganese), in the permeate from the EXXFLOW microfiltration unit.

The treated water pH and alkalinity were extremely sensitive to small changes in alkali feed rate, particularly with the soluble sodium hydroxide. A feed rate of 9 g/L of caustic (100%) was targeted and maintained while the reaction vessel was being filled and treated at a nominal 12 L/min (3 gpm) rate; at this rate an excess of 0.1 g/L (about 1%) would produce 100 mg/L excess alkalinity. In field tests during the caustic runs, aluminum in grab samples increased from 2.5 ppm at a pH of 8.3 to 100 ppm at pH 12 while the alkalinity was 26 ppm and 740 ppm, respectively. Aluminum in lime-treated water was about 18 ppm at a pH of about 10.5 and alkalinity of 90 ppm, and less than one ppm at an 8.8 pH and 44 ppm alkalinity. The amphoteric character of aluminum at elevated pH is well known.

Figure 3-1 shows the relationship between treated water, aluminum content and alkalinity. Alkalinity may be a more

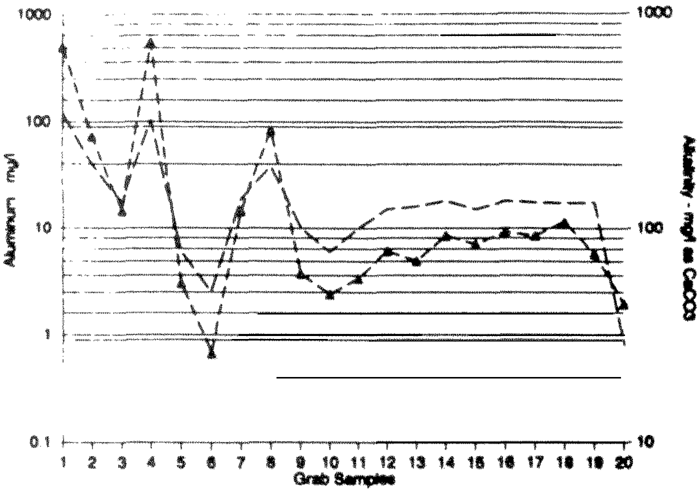


Fig. 3-1 Aluminum-Alkalinity Relationship

important factor than pH based on the grab sample results for caustic and lime treatment. Based on this limited information, at other sites it may be necessary to measure akalinity and choose the precipitating alkali and the rate of introduction so that removal of aluminum (and possibly zinc) is maximized.

Magnesium oxide provided more reliable control due to its much lower solubility at elevated pH, but required a longer time for equilibrium to be reached. Total metal reduction was about two orders of magnitude with magnesium oxide. Some metals, such as copper, were reduced four orders of magnitude.

In some of the tests, residual concentrations of some metals in the permeate were below published solubilities, perhaps due to added benefits attributable to the dynamic membrane, as repotted in other microfiltration studies.

Table 3-1 compares metal concentrations, pH and alkalinity in the feed waters with those in the permeate from the Old No. 8 Seep. Similar results were observed in the single test run using the Richmond Portal seep. Tables C-2 and C-3 in Appendix C provide more detailed information about the test runs.

Table 3-I. Effect of EXXFLOW Microfiltration

Parameter	feed conc., mg/L	permeate conc., mg/L				
		claim	NaOH	$Ca(OH)_2$	MgO	MgO/NaOH
aluminum	700	1.0	36	15	<0.26	<0.5
cadmium	0.5	0.1	<0.006	<0.01	<0.01	<0.02
copper	170	0.1	0.05	<0.025	<0.025	<0.05
iron	2000	1.0	0.3	0.15	0.15	<0.1
lead	0.2	1.0	<0.02	<0.1	0.2	--
manganese	15	0.1	0.01	<0.015	0.27	0.11
nickel	0.2	0.1	<0.03	<0.05	<0.05	<0.09
zinc	60	0.1	0.03	<0.03	<0.03	<0.04
pH	2.3		9.7	10.4	9.3	9.7

The filter cake characteristics during operation of the EXXPRESS varied with the alkali used for precipitation. Solids content was 12% (w/w) with caustic, not up to the claim of 20% w/w solids. With lime, the demonstration produced 30% w/w, not the anticipated **40% w/w** solids. In addition, the cake masses actually recovered during the demonstration runs were considerably less than would be predicted based on run volume, metals removal, and dewatered cake characteristics (Table 3-2). The lower solids content in the filter cakes would be reflected in larger volumes requiring disposal.The relatively low volume runs (600 to 900 gal) and the large water and sludge inventory in the system (400 to 500 gal in the reaction tank and feed tank) apparently allowed for hold-up of heavy sludge within the system. This was confirmed by visual examination of the **conebottomed reaction** vessel at the end of individual runs: considerable solids were observed to be present.

Table 3-2. Filter cake **production** from EPOC **process**

Run no.	alkali	as is filter cake production, lb calculated	measured	% solids
1A	NaOH	279	239	11.6
1B	NaOH	340	264	13.4
2A	$Ca(OH)_2$	343	93	30.3
2B	$Ca(OH)_2$	440	87	32.9
3B	MgO	490	17	27.6
3C	MgO	230	7.5	31.4
4A	NaOH/MgO	300	13	28.4
4C	NaOH/MgO	471	81	20.8

3.3.2 Operational Test Results

For this process, the important operating parameters are the treatment chemical. pH in the precipitation/reaction tank, residence time in the reaction tank, EXXFLOW flux rate, and filter press (EXXPRESS) control. With other wastewaters. there may be other parameters that can affect the performance of the unit. For the demonstration tests, EPOC evaluated each AMD waste stream and selected operating parameters and treatment chemicals based upon bench-scale treatability tests.

Three treatment chemicals were selected for evaluation at Iron Mountain: hydrated lime, i.e., calcium hydroxide or $Ca(OH)_2$, sodium hydroxide (50% liquid caustic soda. NaOH). and magnesium oxide (MgO). Tests were also conducted using a combination of sodium hydroxide and magnesium oxide. Each of these chemicals yielded very different operating and sludge characteristics.

Prcdemonstration shakedown runs were performed by EPOC using hydrated lime. This established the unbuffered quality of this water. In both the predemonstration and the demonstration tests, treated water pH was extremely sensitive to very small changes in chemical feed rate, and very tight control was required to prevent pH excursions of as much as a full unit. The volume and characteristics of the sludge formed presented operating problems, particularly with the EXXPRESS dewatering system, which required considerable attention, including frequent short downtime for manual cleaning.

With sodium hydroxide, the first chemical evaluated during the actual demonstration testing, reaction rates were quick and pH control again was difficult to maintain with highly variable pH results for the permeate during the start-up period of each of the two runs. The sludge generated from the process was very thin and there was some difficulty during the shakedown activities with EXXPRESS unit operation. EPOC evaluated the problems and made adjustments to the EXXPRESS operation in an effort to improve sludge production for the scheduled test. Throughout the demonstration tests, sludge was produced at moderate rates (about 40-50 Ib/hr) and never dewatered to the anticipated 20% solids content

With magnesium oxide as the base, reaction rates were much slower. Approximately 2 hours were required to raise the pH to 8; the low solubility of magnesium hydroxide limits the pH to about 9. This facilitated pH control in the reaction tank and the permeate samples. With good control of pH during precipitation, enhanced removal of aluminum from the permeate from the EXXFLOW was observed. However, sludge recovery for the MgO runs was very low and difficulty was again encountered with operation of the EXXPRESS unit for dewatering during the demonstration test runs. In addition, the physical properties of the sludge produced with MgO were such that it was not possible to form a “chip” or filter cake particle with the EXXPRESS. Instead of adhering to the tube walls. the sludge was easily washed back into suspension when the tubes were opened for draining. Consequently, the EXXPRESS reject continued to concentrate and plug the tubes even as EPOC attempted to vary the flux in the press.

In all cases, the EXXFLOW flux remained essentially unchanged at 2650 $L/m^2{\cdot}day$ (65 $gal/ft^2{\cdot}day$) over the course of each test run. While the runs were not as long as planned, a fall-off in flux would usually occur during the early period if plugging were taking place: that was not the case with these wastewaters and the EXXFLOW unit.

3.4 Ranges of Site Characteristics Suitable for the Technology

3.4.1 Site Selection

The EPOC microfiltration system is readily transportable by truck. The unit size and configuration can be tailored to the needs of the waste stream and the available area on the site or in the treatment plant. The system can either be designed as one large unit or as several replicate modules, depending on site and other needs.

The demonstration test unit (nominal 26 L/min. 7 gpm. capacity) was transported on a trailer approximately 18 ft long and 8 ft wide. This pilot-scale unit was transported to the demonstration test site by a pickup truck over narrow dirt roads. Any site accessible by an ordinary automobile should be accessible to this size unit provided that the roads have sufficient clearance. Larger units would be transported as several individual modules.

3.4.2 Topographical and Area Requirements

A level and stable surface area larger than the unit size (18 ft x 8 ft) is required as well as room for the reaction tank, storage tanks for the feed, permeate, and filter cake, auxiliary equipment, and access. Grade should be no more than approximately 1% and must be able to support the equipment without allowing it to sink or tip. The trailer-mounted unit can clear small obstructions such as rocks or other surface irregularities.

The trailer-mounted unit stands less than 8 ft high and can be placed inside of a building with at least that much clearance.

3.4.3 Climate Characteristics

The ambient temperature can affect the reaction rate of chemicals in the reaction tank. Under the normally-encountered range of operating conditions, no major problems should be experienced. However, perhaps more important is the potential impact of temperatures on flux rate. Cold temperatures can also cause freezing of the sodium hydroxide solution (ii that is the alkali selected), the fecdwater, and the permeate. Mechanical and electrical problems could also be encountered. If the system is to be operated in a cold or freezing climate, modifications to the systems to include heating coils and insulation could overcome such problems. The unit can also be housed in a heated structure to prevent cold-related problems.

High temperatures do not hinder treatment with the technology but may be hazardous to personnel due to the potential for heat stress disorders and contact with heated metal parts.

Weather conditions such as rain or high winds do not immediately damage the technology or prevent its operation. ln areas where the weather is frequently severe or highly variable over the planned treatment time, the unit should be sheltered to prevent damage from continuous exposure to the elements and to ensure consistent operating conditions and consistent product water and solids.

3.4.4 Utility Requirements

The EPOC microfiltration process requires a source of 240 volt. **3** phase electricity. During the demonstration, a portable generator provided the necessary electricity to the process at this remote site; the power could also be drawn from a municipal power grid, if available.

Only a few hundred gallons per day of water for equipment cleaning is required. Water would also be required for emergency purposes and use in an on-site laboratory.

During the demonstration test, a portable compressor was used to supply air for a diaphragm pump and pneumatic valve operation. This requirement could be eliminated by replacing these air-operated components with electric counterparts. When treating some wastewaters, the equipment may need occasional cleaning with hydrochloric acid; during the demonstration, untreated feedwater (2.3 pH) was used for this purpose.

3.5 *Applicable Wastes for the Technology*

The EPOC microfiltration technology may be applicable to many different types of liquid wastes. To be treated with the EXXFLOW and EXPRESS technologies, the liquid waste must have the following characteristics:

- It must be pumpable.
- The contaminants must be in particulate form; the particles must be large enough to be removed by the dynamic membrane, or
- It must be feasible to precipitate dissolved contaminants such as metal ions chemically to allow treatment and removal of the solids.
- Separation must provide an advantage; i.e., the hazardous characteristics of the wastewater must become concentrated in either the sludge or the permeate by the process.

Wastes of varying chemical and physical characteristics can be treated by this technology. The materials of construction of the mixing tanks, the tubing support textiles, and piping can be varied to handle wastes which are corrosive. A non-leachable (by TCLP) solid filter cake can be produced depending on the toxic constituents in the liquid and the chemical additives used.

Acid mine drainage is only one application for the EPOC technology. Other applicable wastes may include contaminated groundwater (dissolved/dispersed metals, fine silt/clay), industrial or municipal wastewaters containing solids and/or precipitable inorganic ion contamination (e.g.. metal finishing); industrial process wastewater (e.g., pickle liquor) for recycle or reuse of the water or solids; and process sludges for production of a dry filter cake, particularly where dewatering by other, conventional means has proven ineffective.

The system is particularly well suited for removal of metals, which tend to form difficult-to-separate sludges and which can be precipitated readily with bases. Case studies reported by the developer (Appendix D) have demonstrated that the system also can treat organic compounds such as oil, grease, pesticides, and kerosene where these can be coagulated or adsorbed on a medium. Other organic pollutants that may lend themselves to the technology could include textile dyes, polymer latexes, fermentation broths, etc. The EPOC technology does not remove volatile organic compounds from liquids but presumably could be used in conjunction with another technology to remove or treat the volatile organic compounds. Evaluation of the system for organic materials was beyond the scope of the site demonstration test and at least laboratory testing would be necessary to evaluate the effectiveness of the technology with any particular waste stream.

In considering applications for the EPOC technology, the required quality of the discharge and solids must be considered, particularly when evaluating the cost-effectiveness of alternatives. Microfiltration, as with the EPOC EXXFLOW, can probably produce a more polished permeate than obtainable by clarification in either a lagoon or a clarifier. Dewatering, as with the EXXPRESS, could be very attractive where the sludge is hazardous, particularly where sludge volume is a significant factor in disposal cost.

3.6 Evironmental Regulatory Impacts

Operation of the EPOC dynamic membrane filtration process for treatment of liquids containing heavy metals and/or other contaminants will require compliance with certain Federal, State and local regulatory standards and guidelines. This technology may be used at Federal Superfund National Priorities List (NPL) sites and other sites. Superfund site regulatory requirements applicable to the use of this technology are discussed below under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Other Federal, State and local environmental regulations are subsequently discussed in more detail as they apply to the performance, emissions and residuals of the technology as evaluated during the demonstration test.

3.6.1 The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for Federal funding to respond to releases of hazardous substances to air, water, and land. Section 121 of SARA, entitled cleanup standards, states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It strongly recommends that remedial actions use on-site treatment that "...permanently and significantly reduces the volume, toxicity, a mobility of hazardous substances." In addition, general factors which must be addressed by CERCLA remedial actions are:

- long-term effectiveness and permanence;
- short-term effectiveness;
- feasibility: and
- cost.

The EPOC dynamic membrane microfiltration technology has been shown to remove >98% of toxic (cadmium, copper and zinc) metals from the contaminated acid mine drainage from the demonstration site. The combined EXXFLOW and EXXPRESS process produced a filter cake which passed the Toxicity Chamcteristic Leaching Procedure (TCLP). The chemical precipitating reaction occurring before the filtration process also raised the pH of the liquid so that the water exiting the process no longer exhibited the characteristic of corrosivity. The removal of the contaminants from the acid mine drainage to the non-leachable filter cake was performed rapidly by the process. Because the contaminants are then separated from the water, this improvement is permanent The contaminants removed are bound chemically and physically in the filter cake solids, as evidenced by the TCLP results.

The EPOC process equipment evaluated during the demonstration was not designed to remove organic contamination, and no volatile compounds were expected in the liquids tested during the demonstration test. The emissions potential in this situation is very low and is limited to the potential for dust emissions while transporting powdered treatment chemicals (e.g., lime). If liquids containing volatile components were to be treated using this technology, a pollutioncontrol system could be used to control emissions, or the volatile contaminants could be removed first using a different technology (e.g., stripping) before microfiltration.

In addition to the above general requirements, Section 121 of CERCLA requires that Superfund treatment actions must meet or exceed "applicable or relevant and appropriate requirements, criteria, or limitation under any Federal law or State environmental statute." Local statutes may also be relevant and appropriate. These criteria, as related to the EPOC microfiltration technology, are discussed below.

3.6.2 Other Federal Regulations

The Resource Conservation and Recovery Act (RCRA) is the primary Federal legislation governing hazardous waste activities. Subtitle C of RCRA contains requirements for the generation, transportation, treatment, storage and disposal of hazardous waste, most of which are also applicable to CERCLA activities.

The use to which the EPOC microfiltration technology was put during the demonstration test would not have been regulated under RCRA, as the acid mine drainage present at the Iron Mountain does not fit the legal definition of a solid waste, of which all RCRA hazardous wastes are a subset. The filter cake produced from the process is a solid waste, and has the potential for being a hazardous waste. However, the TCLP results for the demonstmtion showed that the filter cake produced did not exhibit a hazardous waste characteristic and would not be a RCRA hazardous waste on that basis. Many of the potential uses of the EPOC microfiltration technology would be regulated by RCRA, either because the feed stream would qualify as a RCRA hazardous waste (making all effluent streams hazardous wastes by the derived-from rule), or the filter cake or other effluent could exhibit a characteristic making it a hazardous waste.

If a hazardous waste is treated or generated during treatment with the EPOC microfiltration technology, the responsible party must obtain an EPA generator identification number and comply with accumulation and storage requirements for generators under Title 40, Code of Federal Regulations (CFR) Part 262 or have a RCRA permit or interim status. A hazardous waste manifest must accompany any off-site transportation of the hazardous waste, and transport must comply with Federal Department of Transportation (DOT) hazardous waste transport regulations. Any TSD facility receiving the waste must also be permitted and in compliance with RCRA standards.

The RCRA land disposal restrictions (40 CFR Part 268) require that certain hazardous wastes receive treatment after removal from a contaminated site and prior to land disposal, unless a variance is granted. The microfiltration treatment may allow for disposal of the liquid effluent from the process as non-hazardous This will require evaluation on a case by case basis. The filter cake solids from the microfiltration process may be restricted from land disposal and require further treatment prior to disposal. If necessary, stabilization/solidification may be used to further reduce the mobility of contaminants in the filter cake to below the applicable treatment standard limits. Other treatments may be appropriate depending on the original waste contaminants and the treatment chemicals used.

3.6.2.1 Clean Water Act

The Clean Water Act regulates discharges to surface water through the National Pollutant Discharge Elimination System (NPDES) regulations. These regulations require point-source discharges of wastewater to meet established permit limits or water quality standards The EPOC microfiltration process produces a treated liquid effluent that may be regulated under the CWA if it is to be discharged either directly or to a POTW. If the process effluent were discharged to a surface water body, a NPDFS permit indicating maximum levels of specific parameters would be required. For example, the Iron Mountain Mine AMD would probably be required to meet a pH range of at least 6 to 9.

3.6.2.2 Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) establishes primary and secondary national drinking water standards. These standards consist of Maximum Contaminant Levels (MCLs), MCL goals (MCLGs), and aesthetic standards. MCLs may be applicable and relevant where either surface or groundwater may be used for drinking water. Depending on the disposal options for the treated water from the EPOC microfiltration process, the process effluent (permeate) may have to meet strict guidelines for the amounts of some metal species and water quality parameters.

3.6.2.3 Clean Air Act

The Clean Air Act (CAA) establishes primary and secondary ambient air quality standards for protection of public health. and emission limitations for certain hazardous air pollutants. In most applications no emissions would be expected from the EPOC process: therefore, the CAA would not be applicable. In situations where electrical power to the process equipment may be supplied by fuel-burning generators, use of these generators may be regulated by the CAA. However, State and local standards for diesel exhaust. as well as for nuisance dusts, would be likely to be more stringent, considering the probable size of such equipment.

3.6.2.4 The Occupational Safety and Health Act

The Occupational Safety and Health Act (OSHA) covers the safety of employees in the workplace. OSHA regulations cover the selection and use of engineering controls, safe work practices and use of personal protective equipment at hazardous waste sites. OSHA regulations would cover the use of the EPOC microfiltration technology whether the use occurs at a hazardous waste site or at an ordinary workplace. such as a manufacturing facility. OSHA regulations cover the allowable exposures of workers to chemical hazards, noise, and thermal and electrical conditions regardless of the place the work is occurring. OSHA rules require that training in hazardous waste handling practices be given to all employees who work on hazardous waste sites.

Specifically. work with the EPOC process would certainly require protective measures for spills and leaks of acid and alkali such as the acid mine drainage or the precipitating bases. Protection against dust could also be necessary.

3.6.3 State And Local Regulations

Meeting Applicable or Relevant and Appropriate Requirements (ARARs) may require compliance with State and local law that are more stringent than Federal standards or that may be the controlling standards in the case of non-CERCLA treatment activities. For use of the EPOC microfiltration technology, State and local water quality standards may be the most significant requirements. Water discharge standards can be set based on the use of the water, a site risk assessment, and/or currently available treatment options. When the Old No. 8 acid mine drainage was treated with caustic or lime, **effluent concentrations** achieved through the EPOC treatment system of all metals of concern were below or close to 1 mg/L except for aluminum, and well below 0.1 mg/L for all heavy metals.

3.7 Manpower Requirements

Although the developer believes that the EPOC microfiltration system can be operated with a minimum of oversight, such was not the case during the demonstration tests, at least for operation of the EXXPRESS dewatering unit. As noted in this report, considerable effort was required to adjust cycling and pressure for the EXXPRESS unit and to remove plugs of filter cake to the point where any usable information could be generated. During these tests, two professional staff members were involved almost constantly in these efforts. This would not be practical in a remediation or process application, but it is not clear whether the problems were due to equipment inadequacies, unanticipated and unexplained characteristics of the sludge, or a result of the means of precipitating the metals as hydroxides.

Addition of alkali to precipitate the metals as hydroxides in the reactor vessel also required more than the expected attention since overdosing with precipitant produced pH spikes that were accompanied by elevated aluminum concentrations in the permeate. A more sophisticated pH-controlled alkali feed system and improved agitation might reduce the attention required in this area

3.8 Testing Requirements

It would at first appear that only minimal testing of the feed wastewater stream would be required to develop appropriate processing conditions and precipitant addition rates. However, the difficulties with pH control during the demonstration, even after laboratory and optimization testing with the two wastewaters at the site, suggest that additional information may be needed. For example, it may not be sufficient to add a calculated amount of alkali to precipitate the metals. As noted, alkalinity may play a part in the effectiveness of precipitation. In addition, the physical character of the precipitate may affect the efficiency of separation in the EXXFLOW and, particularly, dewatering in the EXXPRESS. Although the developer indicated that the particles must be larger than 0.1 um to be removed in the EXXFLOW and smaller than 1 um so that they do not plug or blind the EXXPRESS membrane. no tests were identified or run to determine the actual particle size, other than laboratory and field shakedown tests of the system.

Section 4

Economic Analysis

4.1 Introduction

The primary purpose of this economic analysis is to estimate costs (excluding profit) for commercial-scale treatment using the EPOC microfiltration system. With realistic costs and a knowledge of the basis for their determination, it should be possible to estimate the economics for operating similar-sized systems at other sites utilizing scale-up cost formulas. Among such scale-up cost formulas availabk in the literature for chemical process plant equipment is the "six-tenths rule" [1].

This economic analysis is based on assumptions and costs provided by EPOC, on results and experiences from this SITE demonstration, and on best engineering judgement. The results are presented in sufficient detail so that, if the reader disagrees with any of the assumptions made. the reader can draw his/her own conclusions using his/her own assumptions.

Although the SITE demonstration tested the EXXFLOW microfiltration system and the EXXPRESS automatic sludge dewatering system as an integrated unit, the results showed that the EXXPRESS module was ineffective in dewatering the concentrate from the EXXFLOW module, and consequently did not meet the developer's claims. Therefore. for purposes of this cost analysis, an alternate dewatering system was considered for both pilot-scale and full-scale systems. The consequences of not dewatering the concentrate were also investigated for the pilot-scale unit to determine how much of an impact this step would have on costs.

Although the EXXFLOW pilot-scale unit was operated at a permeate flow rate of 3 gpm during the SITE demonstration, it was assumed that it could achieve its design permeate flow rate of 7 gpm. It was also assumed that the performance of full-scale equipment would be similar to that demonstrated with the pilot-scale unit.

Certain actual or potential costs were omitted because site-specific engineering aspects beyond the scope of this SITE project would be required. Certain functions are assumed to be the obligation of the responsible party or site owner and also were not included in the estimates.

Coat figures provided here are "order-of-magnitude" estimates, generally +50%/-30%. and are representative of charges typically assessed to the client by the vendor exclusive of profit.

4.2 Conclusions

- Dewatering the concentrate from the EXXFLOW microfiltration unit before disposal decreases costs for the pilot-scale unit - **\$33/1000** L (\$125/1000 gal) without &watering, compared to **\$27/1000** L (**\$103/1000** gal) with dewatering.

- For the pilot-scale unit, labor, consumables and supplies, and effluent treatment and disposal costs account for about 80% of overall cleanup costs. Site preparation. and startup and fixed costs are the next largest cost contributors Since they are one-time charges, their effect, on a percentage basis, could be reduced for longer duration projects. Annualized equipment costs, utilities, and residuals disposal from the dewatering system contribute the least.

- Treatment costs for the 190 L/min (50 gpm) full-scale unit with dewatering (\$12/1000 L, \$47/1000 gal) are about half of what they are for the pilot-scale unit thus demonstrating the cost advantages of scale-up.

- For the full-scale unit, start-up and fixed costs, labor, consumables and supplies, and effluent treatment and disposal account for close to 90% of total costs. Comparing cost percentages to the pilot-scale unit with dewatering, reductions in labor, and effluent treatment and disposal costs are more than offset by increases in consumables and supplies. Labor shows the largest decrease because manpower requirements are not affected by unit size but rather by the duration of treatment. Residual disposal costs also double due to scale-up, but again this is more than offset by reductions in other cost categories. Site preparation, annualized equipment costs. and utilities contribute the least.

- Although they were not included here, accounting for permitting and regulatory activities, analytical requirements, facility modification, repair and replacement, and demobilization could significantly increase costs.

4.3 Issues *and Assumptions*

This section summarizes the major issues and assumptions used to evaluate the cost of EPOC's microfiltration system. In general, assumptions are based on information provided by EPOC.

4.3.1 System Design and Performance Factors

As stated earlier, the SITE demonstration used an EXXFLOW microfiltration module in tandem with an EXXPRESS automatic sludge dewatering system. Although this system was designed to produce permeate at a rate of 7 gpm. it was operated at 3 gpm during the SITE demonstration. Therefore the estimates for both the 7 gpm pilot-scale and the 50 gpm full-scale units used proportioned flow rates based on results of this SITE demonstration, as shown in the table below:

Unit Size - Permeate Flow Rate

Stream	3 gpm	7 gpm	50 gpm
Influent	50 gpm	50 gpm	833 gpm
Concentrate	47 gpm	43 gpm	783 gpm
Dewater	1.4 gpm	3.2 gpm	23 gpm
Recycle	46 gpm	40 gpm	760 gpm

Details of the calculations used to derive these numbers can be found under the "Effluent Treatment and Disposal" costs section. For this analysis, it was assumed that performance. in terms of percent reduction, for all three units was similar to that tested

Costs for the pilot-scale unit were estimated with and without dewatering of the concentrate stream. Demonstration results showed that the filter cake product from the EXXPRESS unit passed the TCLP test and would be considered non-hazardous for disposal purposes. Although the concentrate stream was not specifically tested during the demonstration, it was assumed that it too would pass the TCLP test and could be considered non-hazardous as well.

For the scenario without dewatering, two further cases were considered. First, it was assumed that the concentrate stream from the EXXFL0W unit, being non-hazardous, could be disposed of on-site. For this case, there would either be no or very little effluent disposal costs. Although this is a very real possibility at the Iron Mountain Mine Superfund Site, it would be a rather rare occurrence at other cleanup sites. Therefore, no costs were included for this case. In a second case it was assumed that disposal of the concentrate stream would be required off-site. Since this a more realistic possibility, this cost was included in this analysis.

The dewatering system selected assumed that solids content could be increased from 1.2% to 20%. The residual filter cake produced was again assumed to be non-hazardous and could be disposed of off-site at a nominal cost.

4.3.2 System Operating Requirements

This analysis assumed that the waste being treated was similar to that tested during the demonstration. The alkali chemical used was assumed to be 50% caustic. Flow rates. the amount of recycle, the type and concentration of contaminants, the type and amount of alkali used, the type and size of dewatering equipment used, if any, will all affect system operation and, consequently, costs.

This analysis assumed a cleanup duration of one year. EPOC projected that one operator could fulfill all operational duties in two hours during a normal 8-hr shift. The rest of the time he/she would be available for other non-EPOC process related tasks. Since the equipment was assumed to operate 24-hr/day, 3 shifts per day, 7 days per week, for 50 weeks per year, labor costs were based on 3 operators being required. EPOC indicated that larger flow units could be built by essentially adding additional microfiltration modules without increasing the labor requirements.

4.3.3 Utilization Rates and Maintenance Schedules

A 90% on-line stream factor was used for costing. Although this was not demonstrated, EPOC feels that this is realistic if design and operational modifications were done and sufficient time for shakedown testing were allowed. They base their contention on prior experience with equipment that is installed and that has been operating for several years in the field. Scheduled maintenance was assumed to be performed during the regular shift.

4.3.4 Financial Assumptions

Annualized equipment costs are based on a 15-year life, 6% simple interest rate, and a salvage value of 10% of the original equipment cost. The time value of money was not accounted for.

The following is a list of additional assumptions used in this study:

- Access to the site is readily available.
- Utilities (electricity, water. sewer hookup, telephone, etc.) are easily accessible.
- The permeate stream will not require any further treatment.
- There are no wastewater pretreatment requirements.

4.4 *Basis For Economic Analysis*

In order to compare the cost-effectiveness of technologies in the SITE program, EPA breaks down costs into the 12 categories shown in Tables 4-1 and 4-2 using the assumptions for each cost factor described in more detail below.

4.4.1 Site Preparation Costs

The amount of preliminary preparation will depend on the site and is assumed to be performed by the responsible party (or site owner). Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, and preparations for support facilities, decontamination facilities, utility connections. and auxiliary buildings. These preparation activities are assumed to be completed in 500 staff hours. At a labor rate of $50/hr, this would equal $25,000.

Although these were not considerations for this SITE demonstration, other significant costs associated with site preparation may include well drilling, preparation and development, as well as buying and installing a groundwater or surface-water pump and associated plumbing, especially if the equipment will be located a considerable distance away from the well. Based on experience from previous SITE demonstrations, the cost to drill, prepare and develop a well was assumed to be $5,000. It was assumed that only one well was necessary to provide the required flow rate regardless of the size of the unit used and that no holding tank was necessary.

The size of the pump also would depend on the size of the treatment system assumed. The pilot-scale 7 gpm unit would probably require a l/4 HP, 10 gpm centrifugal pump, costing about $1,000, while the full-scale 50 gpm unit would probably require a 2 HP, 75 gpm centrifugal pump costing about $3,500, based on the "six-tenths scale-up rule".

Access roads and other site-specific auxiliary structures which may be necessary, such as concrete pads or a building, can be very expensive but are not included here. Therefore, the total site preparation costs for a pilot-scale or full-scale unit would be between $30,000 and $35,000 as shown in Tables 4-l and 4-2.

4.4.3 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner). These costs may include actual permit costs, system health and safety monitoring requirements. and the development of monitoring and analytical protocols. Permitting and regulatory costs can vary greatly because they are site- and waste-specific. No permitting costs are included in this analysis: however, depending on the treatment site. this can be a significant factor since permitting activities are project dependent.

4.4.3 Equipment Costs

The EPOC Microfiltration System assumed for this economic analysis includes a reaction tank, the EXXFLOW microfiltration unit, recirculation pump and associated plumbing, instrumentation, monitoring and control equipment. The size of the reaction tank would be dependent on the size of the EXXFLOW unit and on the alkali used due to different reaction tunes with different chemicals. It would also include an alkali feed system with a feedback control loop to maintain a set pH, a level control, and a mechanical stirrer, the size of which again would he dependent on the size of the reaction tank and the alkali Used.

The cost of rental equipment used in this SITE demonstration such as storage tanks, office trailers, pickup trucks for transporting supplies, diesel generators, air compressors. and forklifts are not included.

Table 4-1. Estimated Costs for 7 gpm Pilot-Scale Unit

COST COMPONENT	without dewatering		with dewatering	
	$	%	$	%
1. Site Preparation	31,000	7.80	31,000	9.45
2. Pamitting & Regulatory	----		----	----
3. Equipment (annualized)	6,500	1.63	6,500	1.98
4. Startup & Fixed	25,650	6.45	25,650	7.82
5. Labor	84,000	21.12	84,000	25.60
6. Consumable & Supplies	101,750	25.59	101,750	31.02
7. Utilities	3,145		3,145	0.96
8. Effluent Treatment & Disposal	145,365		635	
• Dewatering System				
- Capital (annualized)			3,485	
-O&M			63,300	
Total	145,635	36.62	67,420	20.55
9. Residuals/Waste Shipping, Handling and Transport	----		8,600	2.62
10. Analytical			----	----
11. Facility Modification, Repair & Replacement		—		----
12. Demobilization				----
Totals	397,680	100	328,065	100
$/1000 gal	125		103	
$/1000 L	33		27	

Table 4-2. Estimated Costs for 50 gpm Full-Scale Unit

Cost Component	$	%
1. Site Preparation	33,500	3.11
2 Permitting & Regulatory	----	
3. Equipment (annualized)	17,400	1.62
4. Startup & Fixed	91,350	8.49
5. Labor	84,000	7.81
6. Consumables & Supplies	690,900	
7. Utilities	6775	0.63
8. Effluent Treatment & Disposal:	4535	
• Dewatering System		
- Capital (annualized)	12,400	
- O & M	73,450	
Total	90,385	8.40
9. Residuals/Waste Shipping, Handling and Transport	61.780	5.74
10. Analytical	----	----
11. Facility Modification, Repair & Replacement	----	----
12. Demobilization	----	----
TOTALS	1,076,090	100
$/1000 gal	47	
$/1000 L	12	

EPOC estimates the cost of a 7 gpm pilot-scale microfiltration unit, similar to that used in this SITE demonstration, to be about $70,000. A full-scale 50 gpm unit is estimated to cost $187,500. These costs do not appear to follow the so-called "six-tenths rule". Hence, the cost for the full-scale unit appears to be relatively low when compared to the cost of the pilot-scale unit.

The annualized equipment cost is calculated using the following equation and financial assumptions discussed earlier:

$$\text{Capital Recovery} = (V - V_s)\ \frac{i(1+i)^n}{(i+1)^n - 1}$$

where V = the cost of the original equipment
V_s = the salvage value of the equipment.
n = the equipment life (15 years),
i = the annual interest rate (6%).

4.4.4 Startup and Fixed Costs

EPOC's EXXFLOW microfiltration units can be mobile, such as the 7 gpm pilot-scale unit used in the SITE demonstration, or fixed, such as the 50 gpm full-scale unit. Transportation costs are only charged to the client for one direction of travel and are usually included with mobilization rather than demobilization costs. Transportation costs are variable and dependent on site location as well as on applicable oversize/overweight load permits, which vary from state to state. For purposes of this cost estimate, trucking charges will be based on a 40,000 lb, 48 ft long, 8 ft high legal load and will assume that a driver is included. One tractor/trailer is required for the 7 gpm pilot-scale unit while the 50 gpm full-scale unit requires three such tractor/trailers. Assuming that it will cost $ 1.65/mile, a 1,000 mile trip would cost $1,650 for the 7 gpm pilot-scale unit and $4,950 for the 50 gpm full-scale unit

Assembly consists of unloading the EPOC EXXFLOW microfiltration system from the trailers, setting up the system in place, installing instrumentation, hooking up utilities, and other miscellaneous installation tasks. Assembly costs are estimated to be $5,000 for the 7 gpm pilot-scale unit and $15,000 for the 50 gpm full-scale unit.

EPOC estimates that waste-specific testing of the system would require 2 weeks prior to the commencement of treatment. This would involve checking out and troubleshooting each of the systems individually for the particular waste to be treated Two workers would be required for 12 hr/day, 5 day/wk. Start-up costs are assumed to be limited to labor charges at a rate of $40/hr excluding travel and per diem. for a total of $9,600.

Working capital is assumed to be based on the amount of money currently invested in maintaining a one-month inventory of supplies and consumables. The predominant item here is assumed to be treatment chemicals, i.e.. 50% NaOH, at a cost of $30/1000 gal of waste (see Consumables and Supplies). For the pilot-scale unit, the associated cost would be $8,100 (7 gal/min x 60 min/hr x 24 hr/day x 30 days x 0.9 x $0.03/gal) and $58,320 for the full-scale unit.

Insurance and taxes are usually approximately 1% and 2% to 4% of the equipment capital costs, respectively. The cost of insurance for a hazardous waste process can be several times more than this. For purposes of this estimate. insurance and taxes together are assumed to be 10% of the annualized equipment capital costs [3].

The cost for health monitoring programs has not been included here. Depending on the site and the location of the system, local authorities may impose specific guidelines for monitoring programs, the stringency and frequency of which may have a significant impact on project costs.

A contingency cost of 10% of the annualized equipment capital costs is allowed for any unforeseen or unpredictable cost conditions, such as strikes, floods, and price variations [3,4].

The total for start-up and other fixed costs would then be the sum of all of the sub-categories discussed above. i.e.. $25,650 for the 7 gpm pilot-scale unit and $91,350 for the 50 gpm full-scale unit.

4.4.5 Labor

EPOC assumed that after start-up, system operation would be automatic, and require only 2 hr/shift of operator attention to perform routine tasks such as monitoring, routine maintenance, and documentation activities. They assumed a labor rate of $40/hr including overhead and administrative costs. but excluding per diem, travel, and rental car expenses that might be needed if EPOC personnel were to be used. It is the developer's intention to hire and train local people so that they do not incur these additional expenses. The cost and time to hire and train local personnel, which may be substantial, is not included.

The annual cost of labor for both size units is calculated as:
2 hr/shift x 3 shifts/day x 7 days/wk x 50 wk/yr x $40/hr = $84,000.

4.4.6 Consumables and Supplies

Consumables required for the operation of the EPOC microfiltration **system are** limited to treatment, membrane forming. and cleaning chemicals. The cost of membrane-forming and cleaning chemicals arc inconsequential in comparison to treatment chemicals.

For purposes of this economic analysis, caustic soda (NaOH) is assumed to have been used at a dosage rate of 0.15 lb (69 gm) of 50% NaOH per gallon of waste. At $0.20/lb of 50% NaOH. it would cost about $30/1000 gal of waste treated or $95,250 for the pilot-scale unit and $680,400 for the full scale unit. Further cost reductions may be realized if treatment chemicals are bought in bulk quantities. In that case, however, provisions for proper storage and handling must be accounted for.

Based on data from previous operations over a period that reflects operating conditions similar to those experienced during the demonstration tests, the costs for spare parts, including spare microfilters for the EXXFLOW unit, office/general supplies, pump seals. fuses, valve o-rings, and diaphragms are estimated at $2,000/yr for the pilot-scale unit and $6,000/yr for the full-scale unit.

Health and safety gear, which includes hard hats, safety glasses, repirators and cartridges, protective clothing, gloves. safety boots, etc., are estimated to cost **$ 1 ,500/person.**

4.4.7 Utilities

The electricity required for the EXXFLOW microfiltration system is estimated by EPOC to be 5.2 kW for the pilot-scale unit and 11.2 kW for the fulI-scale unit. Assuming no monthly charge and a flat rate of **$0.08/kWhr** for electricity, it would cost 53.145 to operate the pilot-scale unit for a year and 56.775 to run the full-scale unit, both at a 90% on-line stream factor.

4.4.8 Effluent Treatment and Disposal

Two process streams are produced by the EXXFLOW microfiltration system. The permeate is considered to be essentially free of contaminants and is assumed to meet standards appropriate for discharge to a POTW or the local sewer system, at a cost of $0.20/1000 gal. This corresponds to 3.175 million gallons of treated water discharged per year for the pilot-scale unit and 22.68 million gallons for the full-scale unit. The associated costs would be $635 for the pilot-scale unit and $4,535 for the full-scale unit.

The concentrate is the reduced volume portion of the initial wastestream with the enriched contaminants that would require further treatment Based on SITE demonstration test results with caustic soda, 252 lb of filter cake, of which 12.5%. or 31.5 lb (252 lb x 0.125) is solids, were produced from the EXXPRESS unit. This corresponded to an inlet stream of 1.2% solids or 2,625 lb (31.5 lb / 0.012) of concentrate entering the EXXPRESS unit in 240 min. If the density is assumed to be 8 lb/gal. this equals 1.37 gpm (2625 lb/8 lb/gal/240 min). A flow of 1.37 gpm represents 46% of the permeate flow rate of 3 gpm. Therefore, a pilot-scale unit operating at a **permeate** flow rate of 7 gpm would generate 3.2 gpm of concentrate, while a full-scale unit operating at a permeate flow rate of 50 gpm would produce 22.7 gpm of concentrate with 12% solids.

If the concentrate were not dewatered. it could be disposed of off-site as non-hazardous waste at a cost of about $0.l0/gal. This would add an additional $145,000 (3.2 **gal/min x 60 min/hr x 24 hr/day x 7 day/wk x 50 wk/yr x** 0.9 x $0.l0/gaI) to effluent treatment and disposal costs for the pilot-scale unit.

Alternatively. a dewatering system would concentrate the contaminants into a reduced volume filter cake product (estimated at 20% solids). Water from the dewatering step could be recycled, thereby minimizing costs for subsequent transportation and/or ultimate disposal of the filter cake. To highlight how much of a contribution this dewatering step would reduce the overall technology cost, the pilot-scale unit cost estimate includes costs with and without this dewatering **step. The full-scale unit costs were** developed including dewatering.

Plate and frame pressure filtration was assumed to be used for the &watering step. Components of the system include filter plates, filter cloth, hydraulic pumps, pneumatic booster pumps, control panel, connector pipes, and support platform. Installation, engineering, and contingency costs were added to the equipment costs. Installation costs were estimated at 35% of the equipment costs, **while contingency and engineering fees were estimated to be 15% of the equipment and installation costs.** Based **on vendor quotes, capital costs, in** 1989 dollars, were $33,300 for a 32 gpm system **(for the 7 gpm pilot-scale unit), and $118,900 for a 22.7 gpm system (for the 50 gpm full-scale unit). These costs were corrected to 1993 dollars using the annual average** construction cost **index as published in Engineering** News-Record (ENR) magazine. It was 4615 for 1989 and 5210 for 1993, resulting in an index ratio of 1.13. Therefore, the indexed capital costs are $37,600 ($33,300 x 1.13) for the 3.2 gpm system, and $134,000 ($118,900 x 1.13) for the 22.8 gpm system in 1993 dollars.

The annualized capital costs for the dewatering system are calculated in the same way, using the same assumptions as for the EXXFLOW system discussed previously. For the 7 gpm pilot-scale unit this is \$3,485 and for the *50* gpm full-scale unit, \$12,400.

Operating and maintenance costs were based on estimated electricity usage, maintenance, labor, taxes and insurance. The electricity usage and costs were based on a usage rate of 0.5 kWhr/1000 gal and \$0.08/kWhr, and lighting and control energy costs were estimated at \$1,000/yr. Maintenance was approximated at 4% of the capital cost Taxes and insurance were approximated at 2% of the capital cost.The labor cost for the plate and frame pressure filtration system was approximated at \$31,200 per man-year at thirty minutes per cycle per filter press. In 1989 dollars, the operating and maintenance cost for the 7 gpm pilot-scale unit is estimated to be \$56,000 and \$65,000 for the 50 gpm full-scale unit. The corresponding indexed costs in 1993 dollars are \$63,300 and \$73,450, respectively.

An ancillary consideration when using a dewatering system is the additional land area that would be required. It is estimated that approximately 2,500 ft^2 would be required, irrespective of the size of the &watering system used. No costs for this land were included in this estimate.

4.4.9 Residuals/Waste Shipping, Handling and Transport Costs

Waste disposal includes storage, transportation and treatment costs and are assumed to be the obligation of the responsible party (or site owner). The only residuals or solid wastes generated from this process are the filter cake and miscellaneous items (e.g.. used modules. protective gear. etc.).

Since the filter cake generated by the microfiltration system passed the TCLP test, it is considered to be a non-hazardous waste that can be landfilled at a cost of \$0.10/gal, assuming there is no free liquid. For the pilot-scale unit, a concentrate flow rate of 3.2 gpm with 1.2% solids caresponds to 0.038 gal/min of solids being dewatered (3.2 gal/min x 0.012). If the filter cake is 20% solids, then this equals 0.19 gal/min of filter cake being generated (0.038 gal/min/ 0.2). The yearly disposal cost for the filter cake would then be \$8,600 (0.19 gal/min x 60 min/hr x 24 **hr/day** x 7 day/wk x 50 wk/yr x 0.9 x \$0.10/gal Similarly, for the full-scale unit, yearly filter cake disposal costs would be \$61,780.

If. however. the filter cake is hazardous, disposal costs could increase substantially.

4.4.10 Analytical Costs

Standard operating procedures do not require planned sampling and analytical activities. Periodic spot checks may be executed at EPOC's discretion to verify that equipment is performing properly and that cleanup criteria are being met, but costs incurred for these actions are not assessed to the client. The client may elect or be required by local authorities to initiate a sampling and analytical program at their own expense. Therefore. analytical costs associated with environmental monitoring have not been included in this estimate. Specific sampling and monitoring requirements could contribute significantly to the cost of the project.

4.4.11 Facility Modification, Repair and Replacement

Since site preparation costs were assumed to be borne by the responsible party (or site owner), any modification. repair, or replacement to the site was also assumed to be done by the responsible party (or site owner).

Maintenance costs consist of labor and materials and will vary with the nature of the waste and the performance of the equipment, Maintenance labor has previously been accounted for under "Labor Costs". The annual cost of maintenance materials is assumed to be 3% of equipment capital costs and includes provisions for design adjustments and equipment replacement as needed This has already been accounted for in the consumables and supplies cost category.

4.4.12 Demobilization Costs

Site demobilization will include shutdown of the operation. final decontamination and removal of equipment, site cleanup and restoration, permanent storage costs, and site security. Any other requirements will vary depending on the future use of the site and are assumed to be the obligation of the responsible party. No costs have been included for demobilization.

4.5 *Results*

Table 4-l shows the total annual cleanup cost for a 7 gpm pilot-scale system to be \$327,000 (\$27/1000 L) with dewatering and \$397,000 (\$33/1000 L) without dewatering. This is a \$70.000 savings and clearly shows the advantages of dewatering the concentrate from the EXXFLOW microfiltration unit before disposal. Not surprisingly, the largest cost component without dewatering is effluent treatment and disposal (37%). followed by consumables and

supplies (26%), and labor (21%). With dewatering, the largest cost component becomes consumables and supplies (3 1%), followed by labor (27%), and effluent treatment and disposal (21%). In either case, these three cost categories; labor, consumables and supplies, and effluent treatment and disposal, accounted for 75-85% of costs.

The next biggest cost contributors were site preparation (8 to 9.5%), and startup and fixed costs (6.5 to 8%). It should be remembered that this cost estimate is based on a one year remediation. Since these are one-time charges, their respective percentage contribution to costs as well as the overall $/L cost will go down as the length of the project increases.

Annualized capital equipment costs, and utilities each contributed less than 2%. Residuals disposal from the dewatering system accounted for an additional 2.6%. Considering the fact that effluent treatment and disposal costs were almost cut in half by dewatering, this is not a significant contribution.

Table 4-2 shows the total annual cleanup cost for a 50 gpm full-scale system to be $1,100,000 ($12.50/1000 L), including concentrate dewatering. On a $/L basis, this is a two-fold reduction from the corresponding pilot-scale system and clearly shows the advantage of large scale operation.

As in the 7 gpm pilot-scale unit with dewatering, the largest cost component is consumables and supplies (64%). Startup and fixed costs, effluent treatment and disposal, and labor are the next largest cost categories, each contributing about 8 to 8.5%. On a percentage basis, startup and fixed costs stayed about the same compared to the 7 gpm pilot-scale unit with dewatering. However, effluent treatment and disposal, and labor were cut by more than half In fact, the cost category showing the largest reduction is labor, from 26% to 8%. This is because of the assumption that the same number of people would be required to operate the system regardless of size. Only the remediation time seems to affect labor costs. These four cost components; startup and fixed costs, labor, consumables and supplies, and effluent treatment and disposal, accounted for close to 90% of the total.

The cost of residuals disposal increased from about 2.6% for the pilot-scale unit to 5.74% for the full-scale unit because of the-increase in equipment size; i.e., processing more waste produces more filter cake that must be dewatered and eventually disposed of However, this was more than made up by the reduction in effluent treatment and disposal costs. Site preparation, annualized capital equipment costs, and utilities each contributed 3% or less.

This analysis did not include costs for 4 out of the 12 categories, specifically, costs associated with permitting and regulatory activities, analytical requirements, facility modification. repair and replacement, and demobilization. Accounting for these factors could significantly increase costs.

4.6 Development of a 700 GPM Microfiltration System

EPOC has developed a Microfiltration System that is able to treat 2,700 L/min, (700 gpm) of contaminated groundwater with a total metal concentration of 5 mg/L at pH 5. This full-scale unit is designed to be operated as a fixed facility. The vendor has provided the following costs for this system. Major equipment costs are estimated to be $1,350,000. Installation costs include transportation, assembly, and shakedown testing of the individual systems. Installation costs are estimated to be $50,000. Waste specific equipment testing is estimated to require 3 workers for 12 hr/day, 5 day/wk, for 3 weeks. It is assumed that system operations will be automated, requiring only one system operator to run the unit. It is assumed that a maintenance operator will also be required for 12 hr/day. Spare parts are estimated to cost $ 15,000 per year. Assuming that the treatment chemical is 50% NaOH, it is estimated that 250 lb/day of NaOH will be required. The electricity requirements for this unit is estimated to be 59.7 kW, 460 V, 3 phase.

The cost of operating this 700 gpm unit to treat contaminated groundwater with a heavy metal concentration of 5 mg/L at pH 5 is approximately $2.60/1000 gal (if only the costs calculated in this report are considered). This is an approximate estimate based on a total treatment time of 12 months, and using 50% NaOH as the treatment chemical. The cost is significantly lower than the treatment costs of the 7 and 50 gpm units treating acid mine drainage (total metal concentration of 3,000 mg/L at pH 2.3) and relates to the size of the unit and the type of waste being treated.

References

1. Perry, R.H., Chilton, C.H., Chemical Engineer's Handbook; Fifth Ed., McGraw-Hill, Inc. New York, 1973, pg. 25-16.

2. Douglas, J.M., Conceptual Design of Chemical Process; McGraw-Hill, Inc. New York, 1988.

3. Peters, M.S., Timmerhaus, K.D., Plant Design and Economics for Chemical Engineers; Third Ed., McGraw-Hill, Inc. New York, 1980.

4. Garrett, D.E., Chemical Engineering Economics; Van Nostrand Reinhold New York, 1989.

Appendix A

Process Description

A.1 Introduction

The EPOC Microfiltration Process is based upon the ability of a particulate to be retained by a semi-permeable membrane. The physical structure of a membrane is very diverse ranging from solid structures, such as inorganic and polymeric membranes, to transitory or dynamic membranes that are temporarily famed. The EPOC Process may be viewed in three steps:

1) precipitation of metals by adding alkali
2) Concentration of the precipitates by the EXXFLOW microfiltration unit and the production of product water (permeate).
3) Separation and dewatering of the EXXFLOW concentrate in the EXXPRESS unit to produce a semidry filter cake.

The EPOC microfiltration process is a relativity simple process design consisting of a few subassemblies which make up the entire process. These subassemblies are the reaction tank, the EXXFLOW unit, the EXXPRESS unit, and the filter cake dewatering system. Each of these subassemblies is discussed in greater detail in the following sections.

A.2 The Reaction Tank

The chemical reaction to form particles which are large enough to be filtered from the liquid waste stream is the first step in the microfiltration process. Raw water enters the reaction tank and is treated with the alkali of choice resulting in the precipitation of the dissolved heavy metals. The reaction tanks are typically constructed of hard plastics which are inert to the waste stream and the harsh alkaline conditions. The reaction tank used for the SITE demonstration test was fitted with a dry chemical feeder which controlled the dose rate of powdered alkali (such as $Ca(OH)_2$ or MgO). Tanks can also accommodate liquid alkali (50% NaOH solution) with the dose rate being controlled by a metering pump. The dose rate of chemical is set to match the feed rate of the raw water so that the desired pH is maintained in the reaction tank. The reaction tank is sct on level control such that the raw feed rate can be controlled entering the tank. During normal operation, the reaction tank is under steady state and the level in the reaction tank is maintained.

The reaction tank is fitted with a mechanical stirrer that provides agitation to enhance the chemical reaction and prevent excessive solids from settling in the bottom of the tank. Different treatment chemicals exhibit different settling characteristics and, therefore, the stirrer plays an important role in preventing clumping and caking within the reaction tang. Stirring also prevents clumping of solid treatment chemical as it hits the liquid surface in the tank.

Reaction tanks are sired based upon the feed rate of raw water and the flow rates which the EXXFLOW unit can accommodate. The size of the reaction tank and the flow rate of raw water will dictate the residence time for the chemical reaction. The tank must be sized properly to allow sufficient residence time for the precipitation of the heavy metals from solution. For treatment chemicals that have long reaction time, such as MgO. the tank must be large enough to provide for a residence time in excess of two hours. Treatment chemicals such as NaOH react instantly: consequently, the tank can be much smaller.

A.3 EXXFLOW Unit

The EXXFLOW unit is designed to concentrate the solids in the waste stream (reject) and produce clean permeate. This is accomplished thorough crossflow microfiltration. In crossflow filtration. the flow is directed parallel to the surface of the membrane. The EXXFLOW crossflow microfiltration process employs a curtain array of permeable textile tubes, each about I in. in diameter. Resin manifolds are cast onto each curtain end to form modules which are connected to a pump for liquid inlet and to a back pressure valve at the outlet. Liquid feed to the EXXFLOW unit flows from the bottom of the reaction tank. By introducing a controlled liquid flow into the tubes and regulating the outlet pressure, suspended and colloidal matter in the liquid forms a membrane layer on the internal surface of each tube. The goal of a crossflow filtration application is not to trap the components within the pore structure of the membrane. as in unconventional filtration; rather, the large material is temporarily retarded on the membrane and is then swept clean by the crossflow action. Should the quantity or quality of suspended matter in the feed liquid be insufficient or inappropriate to form a membrane, a filter aid material is added to the initial feed to form the membrane. Membranes or filter layers of widely different characteristics can be produced by using different pretreatment chemicals or additives.

After membrane formation, the membrane at the liquid surface **is dynamic, being continually formed and swept** down the length of the tubes by the longitudinal flow of the chemically-treated feed. This cleaning action prevents particles from being trapped within the membrane's matrix and thus substantially adds to its life. To become treated product liquid, or permeate, the feed water filters radially through the membrane layer and out of the textile tube walls for collection. The solids removed from the permeate become **concentrated** and are swept out of the tubes with the remaining liquid, or concentrate. Figure A-l illustrates the EXXFLOW operation.

A uniformly high quality permeate is achieved with the EXXFLOW crossflow microfiltration process. Removal of virtually all suspended solids down to about 0.1 pm has been demonstrated in laboratory and field trials. Other experimental work indicates that the EXXFLOW unit can be developed to produce a low pressure process that will also reject high molecular weight dissolved solids.

A3.1 Dynamic Membrane Concept

The dynamic membrane which is formed on the inner wall of the EXXPLOW tubes is the medium which performs the separation of the permeate from the reject. Suspended solids contained in the feed water deposit on the inner surface of **the porous tubes at a rate which is a function of the fluid** flow rate and backpressure on the module. The deposit on the inside **of the tube wall is called the dynamic membrane.** During the formation of the dynamic membrane, the flow of fluid through the tubes exerts a shear force on the deposited solids that tends to entrain particles back into suspension. After a short period of time, a steady state equilibrium is established at which the deposition rate of solids equals the erosion rate of the dynamic membrane. It is this **dynamic** membrane that actually controls the dynamics of the filtration process. **Pores** of the dynamic membrane are much smaller than pores of the tubes. Suspended solids contained in the feedwater are filtered by the dynamic membrane rather than the tube itself. The **function of the tube is to support the dynamic membrane without allowing** particles to intrude into the tube **matrices.** At the same time the tube must be very porous to minimize resistance to fluid flow.

Physical and chemical properties of the dynamic membrane are also very important to the process. Like the support tube, the dynamic membrane must have a low resistance to the flow of the filtrate. It should be relatively noncohesive so that particles are easily re-entrained by the flow of fluid past the membane, thus minimizing membrane thickness. By adding small quantities of various chemicals, the characteristics of the dynamic membrane can be changed to assist in the filtration process.

A3.2 EXXFLOW Attributes

EXXFLOW crossflow microfiltration units are of modular construction employing a number of manifolded curtains, or modules. Modules are connected together either in parallel or in series with each other, or any number of tubes within a module can be similarly connected.

Two basic configurations of EXXPLOW **units are available: linear, where** a number of curtain modules are suspended with the tubes running parallel to the ground, and spiral, where the modules are wound in a spiral with the tubes parallel or perpendicular to the ground. Curtain modules may also be suspended vertically or supported horizontally. Other variants permit the curtain to be formed into cartridges. Selection of the type of configuration depends on the space requirement and the duty envisaged for the EXXFLOW unit. Wgure A-2 shows a typical EXXPLOW spiral filter module.

Ease of cleaning is an important feature of the EXXPLOW crossflow microfiltration **unit that distinguishes it from other crossflow microfiltration systems. In most cases, cleaning is simply a matter of momentarily stopping the feed, resulting in tube collapse which causes the dynamic membrane material to be dislodged from the tube wall and flushed out with the reject flow. Depending on the configuration of the tubular army, other cleaning systems can be fitted, such as internal ball cleaning, reverse flow flushing, water or air spray jet, or squeeze roller cleaning.**

The EXXFLOW technology is based upon the highly **specialized** woven textile tubular array as **well as on the formation and maintenance of dynamic membranes and cleaning techniques. Currently, the cloth is available in two basic designs, each of which can be woven in any length and**

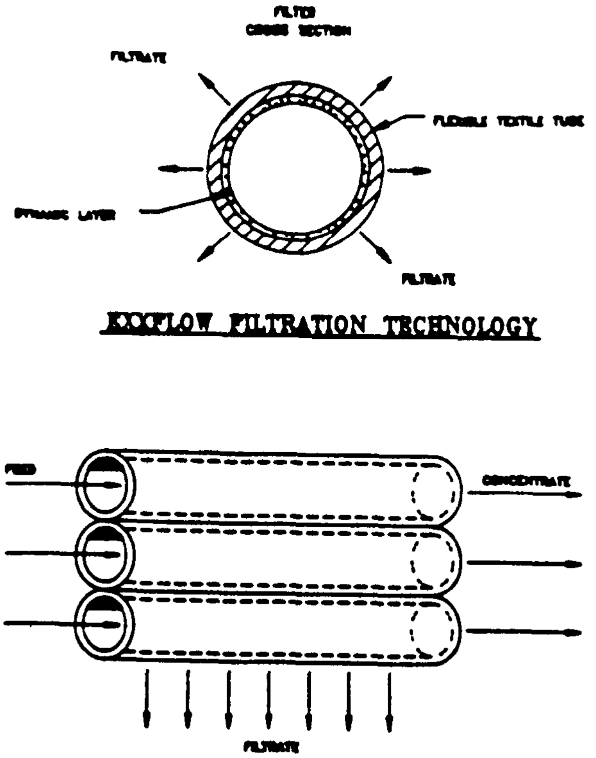


Figure A-l. EXXFLOW Filtration Technology and Flexible Tube Module.

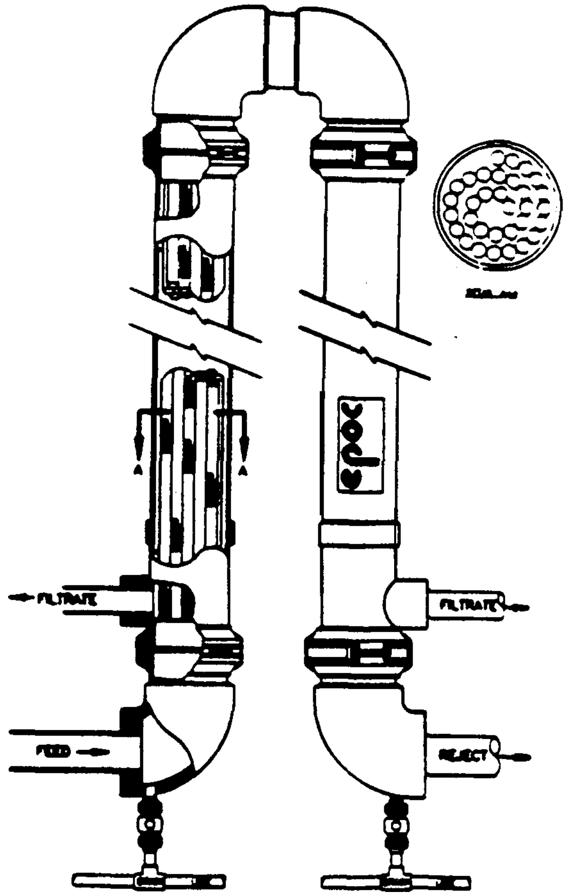


Figure A-2. EXXFLOW Crossflow Microfilter

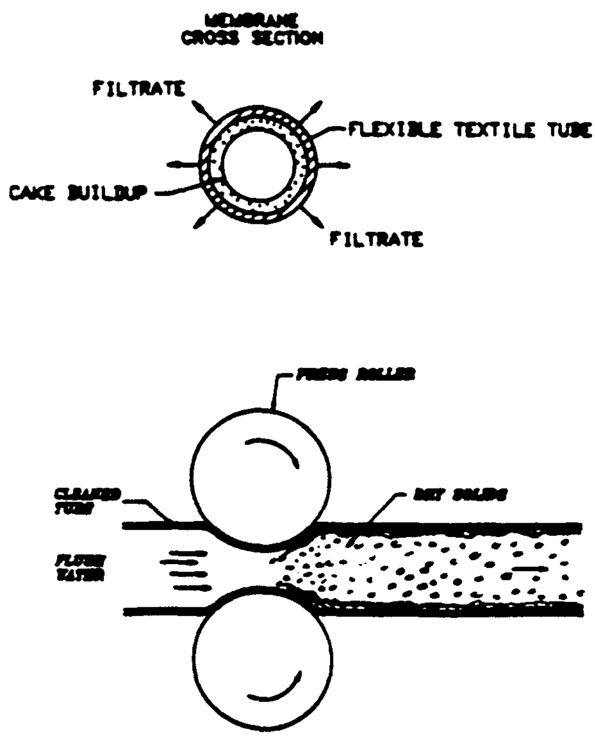


Figure A-3. EXXPRESS Automatic Sludge Dewatering System in any tube diameter desired for specific applications. The porosity or permeability can be varied and post weaving treatments applied to impart specific cloth characteristics. While polyester yarn is the standard material employed. other materials can be used to influence results of the EXXFLGW process depending on the permeate qualities desired for specific feed liquids.

A.4 EXXPRESS Unit

Suspended solids in the water are concentrated by recirculation through the EXXFLOW unit and then the slurry is fed to the EXXPRESS unit. Typical feed to the EXXPRESS units are dilute slurries that contain between 2 and 5% solids. The EXXPRESS units dewater these streams by operating a module in a "dead end" mode by closing a valve at the reject end of the module. Typically. the EXXPRESS microfiltration unit is hung parallel to the ground and is traversed by a set of mechanical rollers. As the concentrated waste stream enters the EXXPRESS module, solids form a thin membrane layer on the internal walls of the tubes similar to that of the EXXFLOW unit. The associated water in the waste stream permeates through the membrane layer and escapes to the outside of the tubes as filtrate. When the membrane layer reaches a controlled thickness, the discharge valve is opened and the exterior of the module is traversed by mechanical rollers. As the rollers traverse the module, the cake that has formed on the wall of the tubes is broken from the surface and flushed from the module.

Water that permeates through the tube wall during the dewatering cycle is recycled to the EXXPRESS feed tank or to the reaction tank. Generally, the water that permeates the EXXPRESS unit needs to be recycled because the filtration is not as effective as the EXXFLOW module.

A.4.1 EXXPRESS Operation

The primary objective of the EXXPRESS is to dewater the concentrated feed entering the unit In normal dead end filtration. the fluid is pushed through the membrane material to remove entrained solids. In this mode. the flow is perpendicular to the surface of the membrane and particles are retained by becoming entrapped within the matrix of the membrane. In the EXXPRESS unit, the dewatering occurs at the tube walls with water flowing radially from the direction of flow down the tube. The EXXPRESS operates automatically in two cycles: load, and cake discharge. In the' load cycle, the discharge valve at the end of the module is closed and fluid enters the EXXPRESS tubes and fitrate begins permeating though the tube walls. As the fluid is discharged though the tube wall, the solids begin to accumulate on the inside of the tubes. As the solids deposit, increased pressure is required to force liquid through the increasing membrane thickness. When the membrane *reaches* a controlled thickness, the discharge cycle begins. The discharge valve is opened and flush water is sent through the tubes while the mechanical pinch rollers begin traversing the EXXPRESS module. Since the inner walls have been coated with solids, the internal tube diameter is decreased, resulting in higher fluid velocities within the tube. As the tube rollers traverse the module, the pinching causes the cake to break from the tube walls and decrease the tube diameter further, resulting in still higher fluid velocities at the rollers. This creates a venturi effect which causes the cake chips to be drawn into the liquid stream and swept from the EXXPRESS module (Figure A-3). The resulting fluid that exits the module contains the solid cake chips and the flush liquid This two phase stream is then pumped to the dewatering screen to separate the solids from the liquid.

The load and discharge cycles are controlled automatically by a process controller. It also allows for manual control of the pinch rollers that traverse the module. The automatic controller also controls opening and closing of the discharge valve.

A.5 Sludge Dewatering

Filter cake dewatering occurs through the use of a gravity dewatering (wedgewire) screen. The dewatering screen has a grating that is small enough to pass the flush liquid but retain the solid filter cake chips. Fluid carrying the cake chips that exit the EXXPRESS unit is pumped directly to the dewatering screen. Fluid that passes though the grating is collected in the EXXPRESS feed tank where it can be recycled to the EXXPRESS for further dewatering. Solids that are trapped on the screen eventually accumulate and fall into a drum or storage container for proper disposal.

There are many designs which can accommodate the dewatering of the sludge. The system described above was used during the SITE demonstration tests. Modification of this design may have been able to produce filter cake with higher solids content The dewatering mechanism should be designed based upon specific process attributes.

Appendix B

Vendor's Claims

This appendix summarizes the claims made by the developer, EPOC Water, Inc., regarding the microfiltration technology under consideration. This appendix was generated and written solely by EPOC, and the statements presented herein represent the vendor's point of view. Publication here does not represent EPA's approval or endorsement of the statements made in this section; EPA's point of view is discussed in the body of this report.

B.1 Introduction

The EPOC microfiltration technology treats wastewater or dilute sludge containing heavy metals to meet stringent discharge limits. Wastewaters of this type range from contaminated groundwater containing 1 to 2 mg/L of heavy metals, through industrial wastewaters containing up to 50 mg/L of heavy metals, to acid mining wastes containing up to 1,000 mg/L. Typically, the industrial wastewaters will also contain particulates, oil & grease and organic materials including solvents and detergents.

The ideal treatment technology has to achieve two functions: first. produce a treated water suitable for discharge and second, produce a small volume of concentrate for disposal or reclamation. The concentrate should be compact so that it passes the RCRA paint filter test and the toxicity characteristic leaching procedure (TCLP).

Other important considerations are:

- operator handling of the waste should be minimized,
- the treatment should be cost effective,
- the system should be robust and versatile providing treatment of a wide range of different contaminants and different concentrations.

B.2 EPOC Microfiltration Technology

The microfiltration technology is a pressure driven separation process for removing suspended solids. particulates and heavy metal precipitates. The microfilter modules utilize a patented flexible woven tube bundle that has excellent chemical and temperature resistance. The modules can be operated in EXXFLOW mode, with a cross-flow tube velocity, or in dead-end EXXPRESS mode, such that the system operates as an automatic tubular filter press. The EXXFLOW mode is used to separate suspended solids and precipitated heavy metals. The EXPRESS mode is used to dewater weak sludges or the concentrate from the EXXFLOW process.

Wastewaters containing dissolved metals are dosed with chemicals to precipitate the metals. Typical chemicals are alkalies such as lime, sodium hydroxide (caustic). magnesium oxide, or sulfides such as sodium sulfide and carbamates. Generally, heavy metals precipitate as their hydroxides within the pH range 9-10 and which alkali to use depends on the waste characteristics and process economics. Sulfide and carbamate chemistry is applicable in the pH range 7-10 and often provides for a higher quality treated water.

B.2.1 EXXFLOW Microfiltration

The EXXFLOW microfilter is a robust and compact unit available in size ranges of 5 gpm to 2,000 gpm. The system consists of a feed tank, recirculation pump, EXXFLOW modules and control system as shown in Figures B-l and B-2. The tubular filter modules are available in various sixes with 10 sq ft to 150 sq ft of filter area to accommodate different plant flow rates. The modules are configured in banks with up to 16 modules per bank.

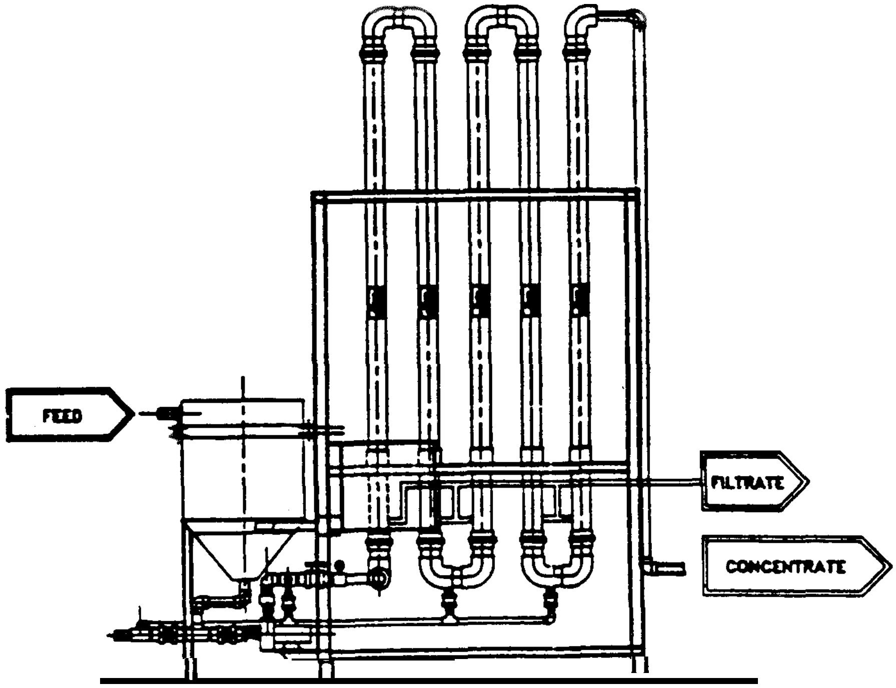


Figure B-l. Typical Vertical Module Configuration.

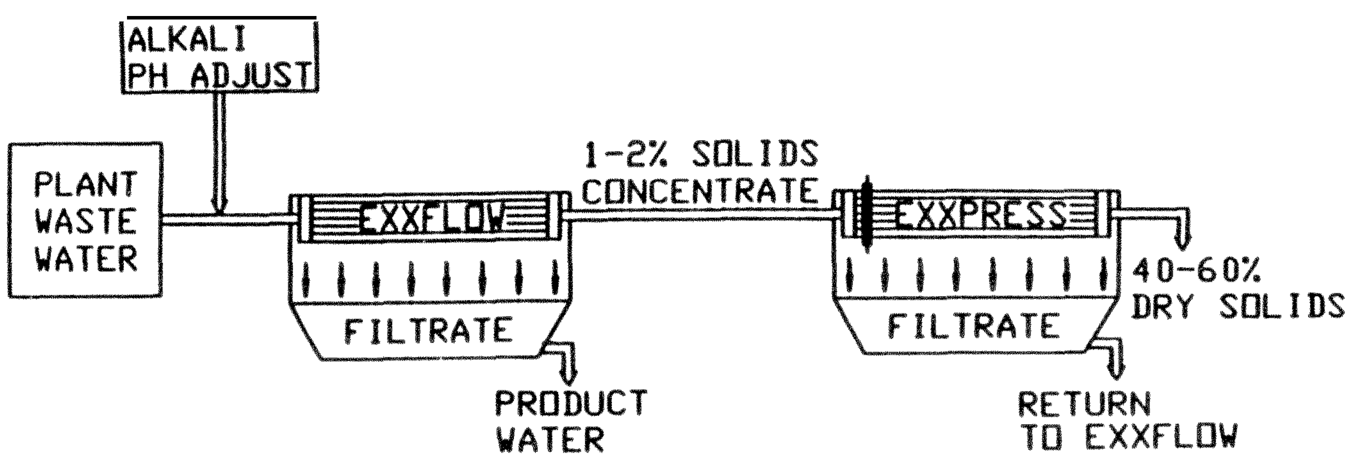


Figure B-2. EPOC Microfiltration Process Schematic.

The feedwater containing the precipitated heavy metals is pumped into the filter module bank(s). The treated Or filtered water is collected in the module housing and discharged.In some applications, pH adjustment is needed prior to discharge. The EXXFLOW modules operate with the wastewater on the inside of the tubes such that the suspended and colloidal matter forms a thin dynamic membrane layer on the internal surface of the tubes. The liquid flow is maintained by the recirculation pump to control the thickness of the layer. Tube velocities of 3 fps to 6fps are typically used. Part of the feed becomes treated water and the remainder(reject) is recirculated to the feed tank.

A concentrate bleed stream removes the solids and precipitated heavy metals from the system to maintain the recirculation loop at 1to5% w/w solids. The concentrate is automatically discharged from the unit and transferred to the solids dewatering unit

Typically the system operation is controlled by a programmable logic controller (PLC). The microfilter is fabricated from corrosion resistant materials: polyester cloth, epoxy end castings and FRP module shells. Operating parameters are 0°C to 65°C (32 to 150°F) temperature range. pH 2 to12 and pressures of 20 to 50 psi.

Periodically the modules are cleaned due to the build-up of impurities at the tube surfaces. The EXXFLOW modules are backwashed by the backwash pump which draws filtrate back through the microfilter tubes. Because the tubes are flexible, they collapse during the backwash operation and break up the impurity layer. Difficult-to-remove foulants are chemically cleaned with acid, hypochlorite. or alkaline detergents.

B.2.2 EXXPRESS Automatic Tubular Filter Press (ATFP)

The ATFP process uses two cyclic operations of solids loading and cake discharge. In the load cycle, the waste is pumped into the EXXPRESS tube module with the reject valve closed. The solids form a thin cake of up to 5mm (3/16 in) on the inside of the tubes. The filtrate is collected in the lower compartment and drained out. The load/dewatering cycle is complete when the pressure inside the ATFP reaches 50 to 75 psi or the load cycle timer is finished The cake discharge cycle then commences by opening the reject valve and traversing the modules with rollers which disrupt the shape of the tube. This disruption causes a venturi action which simultaneously and aggressively causes the filter cake to chip off into the flush stream and also cleans the filter cloth on each cycle. The flush water (same as the feed water) is directed to a wedgewire separating screen. After the cake discharge cycle, the ATFP starts a new load cycle. The flush water is recycled to the front of the system. An EXXPRESS process diagram is shown in Figure B-3.

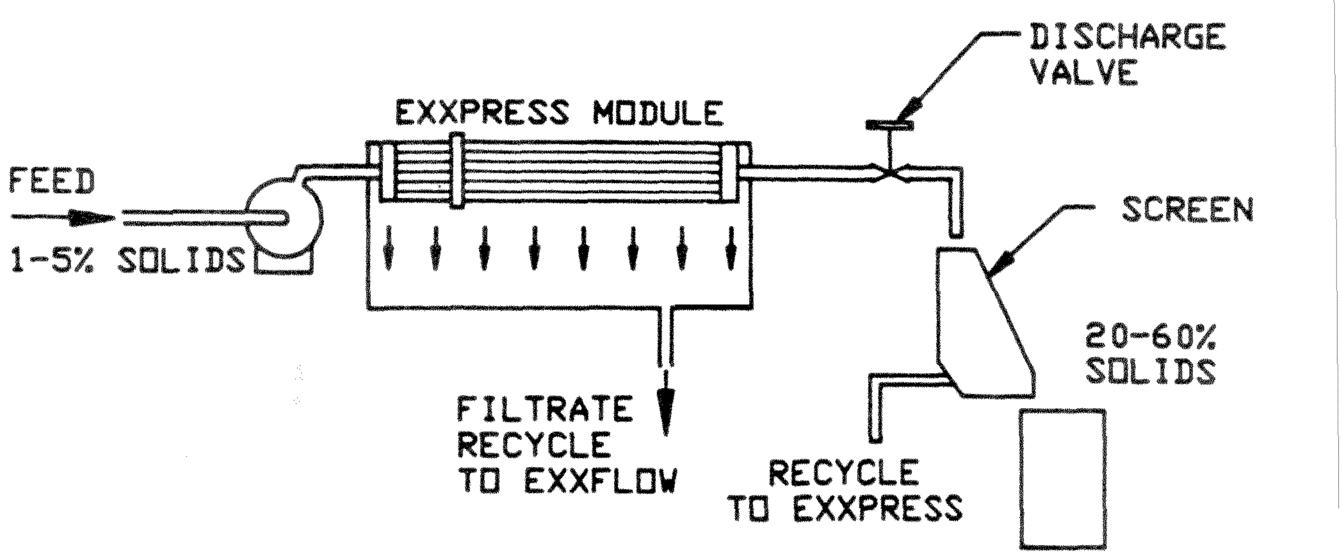


Figure B-3. EXXPRESS Dewatering Schematic.

B.3 Applications of the EPOC EXXFLOW/EXXPRESS Technology

The technology has been successfully applied for:

- removal of hexavalent chromium from contaminated groundwater
- removal of kerosene from aluminum metal ports washer
- removal of nickel solids from electronic industry operations grinding
- removal of dissolved nickel and zinc from plating wastes
- removal of dissolved ethylene glycol, copper, and nickel from manufacturing
- removal of hexavalent chromium. copper, iron, and nickel from electroplating
- removal of iron and manganese from groundwaters
- removal of emulsified oil and iron from oil field waters
- removal of pesticides, arsenic, zinc, and oils from pesticide manufacturing
- removal of lead and other heavy metals from ceramics wastes
- removal of copper particulates from ink wastes
- removal of oil & grease and heavy metals from industrial laundries
- removal of lead from battery manufacture
- removal of heavy metals from hazardous waste treatment facility.

Table B-l provides details of the capability of the technology by industry and by contaminant material.

The EXXFLOW/EXXPRESS system is available as truck and trailer mounted units as well as for permanent installations.

EPOC usually tests all wastewaters before operation to determine the optimal chemical dosages and process parameters.

To date, the process has been applied full-scale mainly to wastewaters containing heavy metals and oil and grease and to contaminated groundwaters. The technology is ideally suited as a pretreatment process prior to other technologies such as activated carbon, air stripping, ion exchange, and reverse osmosis.

Table B-l. Wastes Compatible with the EPOC System

INDUSTRY TYPE	COMPOUNDS
Acid Mine Drainage	Aluminum
Battery Manufacture	Antimony
Ceramics	Arsenic
Chemical Manufacture	Cadmium
Contaminated Groundwater	Chromium
Groundwater Containing Hexavalent	Cobalt
Ch[redacted] and VOC	Copper
Industrial Laundries	Cyanide
Inks	Dyes
Oil Field Wastewater	Inks
Metal Plating	Iron
Paint Pigments	Kerosene
Pesticides	Lead
Weak Sludges from Manufacturing	Manganese
	Mercury
	Nickel
	Oil & Grease
	Paints
	Pigments
	Selenium
	Silver
	Vanadium
	Waste Oil

B.4 System Advantages

The EXXFLOW/EXXPRESS technology has the following advantages over existing systems:

- They provide a combined heavy metal separation and sludge dewatering system.
- The microfilter barrier ensures high quality treated water.
- The microfilter can take high solids and oily feedwater without pretreatment.
- The system is very tolerant to changes in feedwater concentrations.
- Minimal operator attention and handling of sludges.
- Proven cost-effective technology on size ranges from 5gpm to 3 mgd.
- Transportable in the smaller size ranges.

- Modular construction, allowing phased expansion.

- Adaptable to wastes containing 1 to 10,000 mg/L of heavy metals.

- Filter cakes are compact and in most cases pass the TCLP. Wastes can also be further stabilized at the EXXPRESS treatment stage by the addition of fixative agents such as silicates, fly ash, and kiln dust.

Appendix C

Site Demonstration Results

C. 1 Introduction

In January of 1989, Epoc Water, Inc. (EPOC) of Fresno, CA submitted a proposal for their microfiltration technology to the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program administered jointly by the office of Research and Development (ORD) and the Office of Solid Waste and Emergency Response (OSWER). EPA selected the EPOC microfiltration technology for demonstration in the SITE program. Iron Mountain Mine(IMM) in Redding, California was selected by EPA and EPOC as an appropriate site for the technology demonstration. The technology was demonstrated at the IMM site in May and June of 1992. This appendix briefly describes the IMM site and summarizes the SITE demonstration activities and the demonstration test results.

C.2 Site Description

The IMM site is located approximately 9 miles northwest of Redding, California in Shasta County. Figure C-l is a map of the site. For more than 100 years, the IMM site was mined for copper, zinc, iron, silver, gold and pyrite. Mining activities were discontinued in 1962.

As rainfall and groundwater flow on the exposed surfaces of the mining areas, sulfuric acid is produced and high concentrations of aluminum, copper, zinc, cadmium, and iron are released from the mining deposits. The result is acid mine drainage (AMD) which has a low pH due to the sulfuric acid and a high heavy metals content.

Large volumes of AMD flow from the IMM site in several different streams. The IMM site is the worst AMD problem in the country at this time, in terms of total volume of AMD produced and total quantity of heavy metals released. The flow of AMD from Iron Mountain is controlled through use of a reservoir, which prevents too much AMD from entering the Sacramento River. In the past, fish kills and other problems have occurred due to heavy winter rains and overflow of the reservoir.

Several acid mine drainage streams exist on the site. Five major sources account for the majority of the copper, zinc, cadmium and iron that migrate from the site. These five sources of AMD are: the Richmond Portal and the Lawson Portal, which discharge into Boulder Creek; and the Big Seep, Old No. 8 Mine Seep and the Brick Flat Pit Bypass discharging into Slickrock Creek. The two streams chosen for the demonstration were the Richmond Portal and the Old No. 8 Mine Seep.

C.3 Wastewater Contamination Characteristics

Both the Richmond Portal and the Old No. 8 Mine Seep had high levels of aluminum and iron. with some arsenic, cadmium, copper, lead, magnesium, manganese and zinc. The concentration of iron in the Richmond Portal WY approximately 20,000 mg/L with a pH of 0.6 and a conductivity of 195,000 µmhos/cm. The Old No. 8 Seep had an iron concentration of approximately 2,000 mg/L with a pH of 2.3 and a conductivity of 8,000 µmhos/cm. The Richmond Portal liquid had a pale green color and both streams had a characteristic metallic odor.

C.4 Review of SITE Demonstration

The Site Demonstration was divided into three phases: 1) site preparation, 2) technology demonstration. and 3) demobilization. These activities and a review of the technology and equipment performance during these phases are described below.

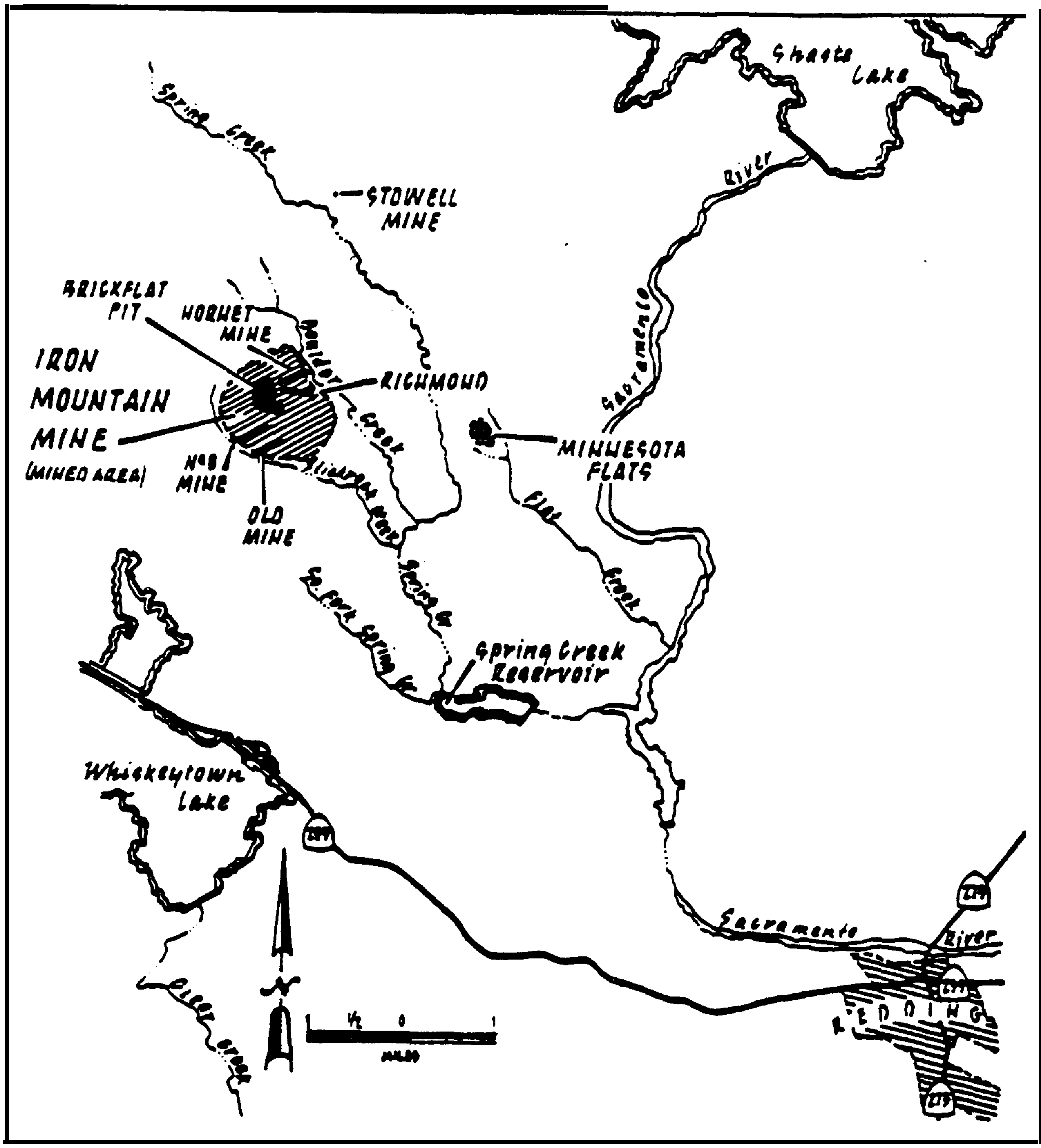


Figure C- 1. Iron Mountain Mine Location Map Showing Richmond Portal, Old No. 8 Mine Seep and Other Point and Nonpoint Sources.

C.4.1 Site Preparation

A level area of approximately 1,000 sq ft was selected near the flume that contained water from the Old No. 8 Seep. The test site was located within 50 yd of the location where the Old No. 8 Seep percolated from the ground. An office trailer was brought on site along with a portable toilet. Five polyethylene storage tanks (capacity of 6000 L or 1,600 gal each) were brought to the site and leveled in the area

Plywood was used to create a "floor" on which quipment could be leveled and set up. The plywood also created a building platform to which equipment such as pumps, tubing and flow meters could be anchored. To obtain test water, a gravity syphon was created by connecting a line from the Old No. 8 flume and the storage tanks. This produced a continuous source of raw feed during the demonstration test.

C.4.2 Support Equipment

Support equipment for the microfiltration system included storage tanks for the treated and untreated acid mine drainage and for clean water, a generator and compressor for power and compressed air, and a forklift for material handling. Specific items include:

- Five 6000 L (1,600 gal) polyethylene tanks for storage and volumetric measurement of the feed and treated water,
- Two platform scales for weighing filter cake and treatment chemicals,
- An office trailer approximately 20 ft by 8 ft with two rooms for shelter, storage and the field laboratory,
- A 1600 L (425 gal) polyethylene water wagon/truck tank for water transport,
- A 3/4 ton pickup truck for transporting supplies, fresh water. and for transportation of the Richmond Portal water to the test site,
- A cellular phone for emergency communications, laboratory communications, ordering supplies and scheduling deliveries,
- A 20 kW diesel generator with 3-phase 240 volt 60 hz capacity to power the process equipment, and single-phase 110 volt service for the support equipment and the field trailer,
- An air compressor with a capacity of 100 scfm for pump and pneumatic valve operation,
- A heavy duty construction forklift for filter cake handling and treatment chemical handling,
- Several 55 gal drums to contain the filter cake from the process.
- Transfer pumps for the liquids,
- A sump pump for collecting water,
- Analytical equipment for measuring field parameters,
- Piping and flow meters for measuring liquid flow rates and volumes,
- Several gas cans for transporting gas and diesel to fill the compressor and generator,
- Extra lumber for constructing pipe and flow meter supports, and
- Miscellaneous hand tools, including a hammer. wrenches and screwdrivers.

C.4.2.1 *On-Site Support Services*

Field sample analyses were performed in a two-room field trailer. Half of the trailer was used as the laboratory. while the other half provided air-conditioned shelter for the field crew as well as storage for supplies and equipment. A portable computer and printer were used for data processing. There were no other support buildings or services available on-site.

A forklift was brought to the site to facilitate the handling of the sludge filled drums. The forklift was also used to move pallets of treatment chemicals and the liquid sodium hydroxide drums.

C.4.2.2 Utilities

Utilities required for the demonstration included water. electricity, phone service and compressed air. Since no utility lines were available at the demonstration site, all utilities were provided through portable means. A 20 kw diesel generator was used to provide electricity to both the microfiltration process equipment and the field trailer Three phase, 240 volt power was supplied to the process equipment. and single phase. 120 volt power was used for the trailer and miscellaneous support equipment Compressed air was provided by a gasoline-powered compressor with a capacity of 100 scfm.

Fuel for both the generator and the compressor, purchased at a service station in Redding. was brought to the site each day in gasoline cans using a rented pickup truck. This same truck, outfitted with a 425 gal tank, was used to transport **non-potable water** for equipment **decontamination and process** needs to the site from a clean water source located elsewhere on **Iron** Mountain. Water was stored in 1,600 gal tanks at the test site. Potable water for drinking was purchased in bottles and brought to the site. Reagent-grade water for cleaning sampling equipment and performing field blanks was purchased from a laboratory supply house.

Telephone service was provided by a cellular phone rented for the demonstration. This telephone was required for ordering supplies, scheduling deliveries, maintaining contact with the analytical laboratory and home offices and for emergency communications. The nmote location of the site made the acquisition of a portable telephone vital to the safety of the field crew.

C.4.3 Technology Demonstration

This section describes the operational and equipment problems and **health and safety issues associated with the SITE demonstration.**

C.4.3.1 Operational *Problems*

The SITE team **experienced operational** problems during the **demonstration. Some** of these problems resulted in changes to the **demonstration** schedule, duration, and number of test runs performed. Other problems required decisions to be **made in the** field to solve them. These operational problems and their resolutions are described below:

- The Iron Mountain Mine Site is fairly remote and reachable only by narrow dirt road. Transportation of equipment to the site required extra care and planning. All utilities required on the site had to be supplied through portable items. Access to the Iron Mountain Mine site is controlled through several locked gates along the road; supplies could only be delivered when **a member** of the field team carrying a key was present at the outermost gate to provide access. At least an hour was required to drive between the nearest sources of equipment and the site. These access problems required additional planning and personnel to ensure needed supplies were on site and to avoid delays.

- The developer required a much longer initial shakedown period than initially anticipated. Both mechanical and chemical problems occurred for several weeks, delaying the commencement of the **demonstration test.** Even after **testing had** begun, some days of testing had to be aborted due to equipment problems. The demonstration test unit was continuously modified and changed in the field throughout testing. The number of test runs to be performed was reduced significantly after several weeks in the field had passed and several repeated failures of the EXXPRESS unit had occurred. All but one of the runs using Richmond Portal water as the feed were eliminated.

- Samples could not be shipped **the same** day due to the long days at the test site. Samples were shipped the morning following their collection by overnight courier service.

- It was considered unsafe to travel the road from the Iron Mountain Mine site after dark. This, as well as the 1 hr travel time to the site or back, cut down the available time for testing each day.

- The startup time for the unit was **much longer than anticipated by the** developer, hence, the 8 hr runs originally planned were decreased to 6 hr in order to be able to complete the sampling activities. In fact, most of the demonstration runs lasted about 4 hr. These changes resulted in modifications to the original sampling plan.

- During one day of the demonstration test, access to the site was blocked completely due to a truck accident (not related to this project) and the resulting cleanup on the road to the site. No testing could be performed on that day.

- Since the demonstration testing period was much longer than originally planned and the developer's personnel had another commitment to fulfill, a three-week-long hiatus occurred before the testing could be completed

- The process unit had to be drained and cleaned each day to prevent settling, scaling and fouling of the process equipment. The nightly cleaning may not have been required if the unit were operated continuously.

C.4.3.2 Equipment Problems

The SITE team experienced many equipment problems during the demonstration test. These problems resulted in: (1) repeating the affected demonstration test runs, (2) eliminating several planned runs, (3) on-site equipment maintenance and **modification,** and (4) changes in the demonstration schedule and duration.

- **The equipment that was** brought on site was different from that originally described in the testing documents. A source of compressed air to operate a diaphragm pump was required that had not been planned or acquired. During testing in cold temperatures, the pneumatic pump began to stall as ice accumulated on the discharge manifold An air drying mechanism was installed to prevent freezing of the pump parts.

- Several electrical and mechanical problems with the equipment occurred during shakedown requiring maintenance, modification of the equipment. and acquisition of additional and replacement parts. Electrical problems were most likely due to inclement weather conditions experienced during shakedown and testing. The developer had to bring an additional person to the field to assist with operation and maintenance of the equipment.

- The feed water (Old No. 8) did not react with the treatment chemicals instantaneously and the mixture did not behave as anticipated by the developer. Control of the pH of the treated feed and the permeate required time for trial and error; on some days samples could not be collected. Poor control led to inconsistent permeate output.

- Repeated problems with clogging of the EXXPRESS filter tubes occurred requiring many changes to operating procedures and equipment configuration. These problems also resulted in equipment downtime and aborted runs.

- The dewatering screen for the filter cake did not perform as well as anticipated. More water was retained in the filter cake than was felt to be representative of the process operation. Minor modification of the screen helped but did not eliminate this problem.

- A basket strainer was installed to remove large clumps of solids before fluid was fed to the EXXFLOW unit.

C.4.3.3 Health and Safety Considerations

In general, health and safety hazards associated with this demonstration test were physical in nature. The pH of the Old No. 8 stream was about 2.3 and that of the Richmond Portal stream was 0.6. These highly acidic liquids presented a hazard to personnel through splashing on the skin or in the eyes. Lifting of heavy items and working with and around the operating equipment were additional physical hazards as were the hazards associated with tripping or slipping on the uneven and rocky ground surface.

Heat stress was a major concern during much of the demonstration activities as temperatures in the area **were in** the 80s and 90s during most of the demonstration testing. The hazard was increased by the need to use protective clothing that reduced evaporation from the skin and added additional weight to the personnel. The air conditioned trailer and the availability of cool potable liquids were very important in the prevention of heat stress disorders.

Other hazards of the site included: fire and explosion hazard from the liquid fuel on site for the generators; potential exposure to sodium hydroxide which is corrosive and powdered lime which can be a respiratory irritant; insects and animals prevalent at the site: and exposure to inclement **weather** (hail,thunderstorms). The remote location of the site provided the additional hazards associated with driving along the narrow dirt toads and the unavailability of nearby assistance in case of emergency.

Personnel were required to wear protective clothing appropriate to the tasks being performed. Steel-toed boots were used in all areas on site. Chemical resistant boots were used during any tasks with potential contact with the low pH feed liquids. Modified level D protection was used during sample collection, including hard hat, faceshield, latex inner gloves and nitrile outer gloves. Sampling and handling of the Richmond Portal liquid was performed by personnel wearing splash repellant full-body coveralls and goggles with a faceshield in addition to the hard hat and gloves. For field laboratory analyses, goggles, latex or nitrile gloves, and a splash apron were worn as a minimum. Dust masks were worn when transferring the 50 lb bags of lime to the feed hopper. No other respiratory protection was required on this site because no volatile compounds were present in the waste liquids.

C.4.3.4 Site Demobilization

The process equipment was drained, decontaminated and removed from the demonstration site after testing was completed All of the piping and pumps were disassembled. Some of this equipment was decontaminated for reuse on other sites. while materials that were contaminated or damaged were disposed of. Equipment and tools to be retained were sent off-site for storage. All of the rental equipment was returned, including the trailer, generators, forklift and platform scales. The site was later cleared of any remaining debris.

The drums of filter cake were to stay on site; they were transported to another area on Iron Mountain for permanent storage. Other contaminated materials, including used personal protective equipment. were placed in drums for off-site disposal. The storage tanks, which had become contaminated and weathered, were cut into pieces and drummed for off-site disposal. A total of 12 drums was sent to a hazardous waste landfill.

C.4.3.5 Experimental Design

The objectives of the technology demonstration were to 1) assess the technology's ability to remove toxic metals present in the acid mine drainage (AMD) waters, viz. Old No. 8 Mine Seep and Richmond Portal, at the IMM site. with a 90% confidence level, to residual levels claimed by the developer (see Table C-2), and 2) evaluate the system's ability to dewater the metals-bearing sludge resulting from the separation of precipitated metals and the treated water to solids concentrations >20% for NaOH treatment and >40% for lime treatment.

These objectives were achieved through a carefully planned and executed sampling, analysis and monitoring plan, but with changes which were implemented in the field as a result of process and operational modifications made by the developer either just prin to the start of the demonstration. during the testing, or as a result of some operational problems encountered.

The EPOC microfiltration technology was tested on two AMD streams. the Old No. 8 and Richmond Portal. It is known from conventional metals precipitating processes that for a given wastewater stream consisting of an array of metals at different but more or less steady concentrations, there exists an optimum pH for a given precipitating agent at which an optimum residual metals concentration in water is realized. These optimum pHs and required reaction times for the treatment of Old No. 8 and Richmond Portal with lime. caustic and magnesium oxide were established through beaker tests by EPOC at its Fresno, CA facility prior to the start of the demonstration. Therefore, the only parameter that was to be varied to evaluate the technology was the selection of precipitating agent(s). The demonstration runs conducted on the two AMD streams are described in terms of the precipitating chemical(s) and the actual flow rates, run time and volume treated, and are presented in Table C- 1.

In order to achieve the demonstration objectives, solid and water samples were collected from the EPOC microfiltration system and were analyzed for a number of critical and non-critical parameters. These parameters had been further categorized as process or analytical and as off-site laboratory or field determined. Metals (i.e., Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Mo, Ni, and Zn), pH and total solids of the water samples and the metals, pH and moisture content of the filter cake solids were considered critical analytical parameters, and the flow rates and total volumes of the water streams and the mass rate and total mass of the solids streams were considered critical process parameters. Non-critical measurements that were also performed included total dissolved solids, acidity or alkalinity, sulfate, temperature and conductivity, turbidity and dissolved oxygen of the water samples and density and toxicity characteristic leaching procedure (TCLP) for metals in the filter cake solids. In addition, electrical consumption and system pressure were also monitored. EPA-approved sampling, analytical. quality assurance, and quality control (QA/QC) procedures were followed to obtain reliable data. The Technology Evaluation Report provides and/or summarizes all results.

C.4.3.6 Review of Treatment Results

This section summarizes the results of both critical and non-critical measurements for the demonstration of the EPOC microfiltration technology and evaluates the technology's effectiveness in treating the acid mine drainage streams contaminated with heavy metals.

Summary of Results for Critical Parameters

The SITE Demonstration test was conducted at the Iron Mountain Mine Superfund Site, in Redding, CA. This site is contaminated with several water sources that are laden with heavy metals. Two water sources were tested during the demonstration; which are known as Old No. 8 Mine Seep (ON8) and Richmond Portal Seep (RP). Both acid mine drainage streams are contaminated with high ppm levels of iron, aluminum, copper, and zinc. Several other metals were present at much lower levels but were still considered critical in the evaluation of this technology.

Test runs were made using three treatment chemicals on water collected from the Old No. 8 seep and a combination of two chemicals was evaluated on water from the Richmond Portal Seep. Test runs averaged about 4 hr in length during which samples were collected of the raw feed, permeate, and filter cake. Samples were composited for each of the parameters based upon a weighted average of the flow rate and production rate of filter cake. Several grab samples were also obtained during each run. Samples were analyzed primarily for metals to determine removal efficiencies and the fate of the heavy metals. Results for the treated effluent (permeate) are summarized in Table C-2.

The first series of tests were performed in duplicate on water obtained from the Old No. 8 seep with 50% sodium hydroxide as the precipitating agent Average feed concentrations of aluminum, copper, iron and zinc were approximately 700, 170, 2000 and 60 mg/L (ppm). respectively. Results the permeate composite samples

Table C-1. EPOC Demonstation Test Runs Performed at IMM Site

Stream	Precipitating Chemicals	Test Run #	Raw Feed Rate, gpm	Chemical Feed Rate, gm/min	Run Time, min	Treated Volume, gal
Old No. 8	Caustic, 50%	1 A	3.0	208	238	774
	Caustic, 50%	1 B	3.0	206	241	756
	Lime	2 A	3.7	103	303	949
	Lime	2 B	3.4	95	307	901
	Magnesium Oxide	3 B	3.5	100	312	917
	Magnesium Oxide	3 C	3.1	88	242	714
	MgO/Caustic	4 A	3.5	47/87	253	626
	MgO/Caustic	4 C	2.9	40/111*	238	746
Richmond Portal	MgO/Caustic	5 A	1.0	38/272*	238	210

* 40 gm/min MgO/111 gm/min 50% NaOH

Table C-2. Treated Effluent Quality

	Old No. 8 Mine Seep, Permeate Composite Conc., mg/l						Richmond Portal Treatment		
Analyte	Feed Conc., mg/L	Developer's Claim Permeate Conc., mg/L	TEST 1 Caustic	TEST 2 Lime	TEST 3 Mg Oxide	TEST 4 MgO+ Caustic	Feed Conc., mg/L	Developer's Claim Permeate Conc., mg/L	TEST 5 MgO+ Caustic
			Permeate Composite						Permeate Composite
			Conc.,mg/L	Conc.,mg/L	Conc.,mg/L	Conc.,mg/L			Conc., mg/L
Aluminum	700	1.0	36	15	<0.26	<0.5	2100	1.0	<0.360
Arsenic	0.1	0.2	<0.03	<0.015	<0.015	<0.015	54	0.2	<0.015
Cadmium	0.5	0.1	<0.01	<0.01	<0.01	<0.02	15	0.1	0.4
Chromium	0.07	0.1	<0.01	<0.02	<0.02	<0.04	0.4	0.1	<0.03
Copper	170	0.1	<0.03	<0.025	<0.025*	<0.05	300	0.1	<0.035
Iron	2000	1.0	0.27	0.12	0.16	<0.1*	21000	1.0	14
Lead	<0.2	1.0	<0.02*	<0.1	**	**	4	1.0	**
Manganese	13.3	0.1	0.01	<0.015	0.27	0.065***	21	0.1	3
Molybdenum	0.11	0.5	<0.03	<0.04	<0.04	<0.1	5	0.5	<0.085
Nickel	0.18	0.1	<0.03	<0.05	<0.05	<0.08	<1	0.1	<0.07
Zinc	60	0.1	0.03	<0.04	<0.03*	<0.04	1800	0.1	<0.045
pH	2.32	N/A	10.2,-	10.4, 9.7	9.8, 8.9	9.7, 9.8	0.6	N/A	8.2

* grab sample average.

** lead analyses in these tests rejected.

*** single run, aerated.

for both tests indicated that all metals were reduced to levels less than the claimed 1.0 mg/L or 0.1 mg/L objectives with the exception **of aluminum, Results for aluminum in the composite samples for the first and second test were 61 and 12** mg/L respectively; iron concentrations in the composite samples of the permeate were 0.27 mg/L and 0.15 mg/L; below the **developer's claim of 1 mg/L.** Although aluminum was not reduced below the vendor claim of 1 mg/L, reductions of 91% and 98% were observed in the two test runs. The high residual aluminum was probably caused by the **difficulty encountered in controlling the pH in the** reaction tank. The improved reduction in the second run can be attributed to the process operators becoming more **familiar with pH control and operational characteristics required to treat this water.**

Similar results were observed in the succeeding tests with the Old No. 8 Mine Seep and lime, magnesium oxide, and the mixture of magnesium oxide and caustic, with some notable exceptions. These results are also presented in Table C-2. SpecificalIy, reduction of aluminum to <l mg/L was achieved with the magnesium oxide and the mixture of magnesium oxide and caustic, but not with lime. Iron was reduced further below the 1.0 mg/L objective, to about 0.1 mg/L, with lime, magnesium oxide, or magnesium oxide/caustic. And. while lead remained below the objective, 1.0 mg/L, in all tests, the removal appears to be less complete with magnesium oxide than with caustic or lime. Similarly, manganese removal was less complete with the magnesium oxide, Because of the low concentrations of several of the metals in the feed water, it is not possible to discern differences in removals of these metals with the different bases.

All tests with the Old No. 8 Mine Seep were carried out at a flow rate of about 3.0 gpm, (see Table C-l) and discharged permeate at essentially the same rate throughout the approximate 4 hr of treatment, within the limits encountered due to forced interruptions and other factors. The original plan was to use a flow rate of approximately 7 gpm. but operational problems made this rate unachievable with this wastewater.

Table C-2 also indicates the elevated pH values observed in the permeates from all the tests. It is unknown whether more precise pH control would have affected permeate quality, sludge production, or sludge **quality. Another question that remains unanswered is whether the permeate would have precipitated additional solid if** it were re-neutralized to a pH of **<9.0** for discharge.

When a mixture of magnesium oxide and caustic was used to precipitate the metals from the Richmond Portal AMD, high removals of all heavy metals and aluminum were observed whik iron and manganese failed to meet the developer's claims of 1 .0 mg/L and 0.1 mg/L. respectively. Nevertheless, with an initial concentration **of 20,600 mg/L iron, 2140 mg/L aluminum, and 399 mg/L copper. the precipitation and microfiltration were very effective in removing** metals. The raw feed flow rate for this single test was approximately **1 gpm and permeate flow rates were slightly higher,** about 1.25 gpm. **Permeate pH was <9.0.**

In addition to affecting the residual metal content in the permeate, the choice of base also affected the solids content in the sludge and. consequently, in the filter cake. This also affected the efficiency and operational effectiveness of the EXXPRESS microfiltration unit. The sludge from the caustic treatment was clearly more fluid than that from either lime or magnesium oxide, presented greater operating difficulties in the EXXPRESS, and resulted in significantly lower solids content in the resulting filter cakes. None of thefilter cakes, regardless of base used. achieved the claimed minimum solids content, 20% with caustic and 40% with lime (or magnesium oxide). In addition, the calcium sulfate coprecipitated with other metals when using time appears to add further operational difficulties to sludge dewatering in the EXXPRESS. It remains the **developer's opinion that the** EXXPRESS system **could be optimized to overcome these difficulties and achieve the objectives.**

In addition to lower-than-expected solids content in all filter cakes from the EXXPRESS, the total mass of solids recovered from all tests were significantly lower than anticipated by calculating the theoretical solids available and comparing to the weights and solids content **of the filter cakes as recovered. Visual examination of the system indicated that significant volumes of solids were retained** in the system, both settled in the reaction **vessel and dispersed in the liquid retained in the system.**

A compilation of the data for the several tests is presented in Table C-3 **and more detailed information on the filter cake yields is summarized in** Table C-4.

Table C-3. EPOC Microfiltration Results Summary

	Old No. 8 Mine Seep				Richmond Portal
	Caustic Treatment	Lime Treatment	Magnesium Oxide Treatment	Mg0 + Caustic Treatment	MgO + Caustic Treatment
Feed Wastewater pH	2.17	2.33	2.5	2.4	0.6
Treated water pH	9.74	10.4	9.31	9.8	8.5
Total metals Removed, %	98.8	99.56	99.97	99.95	99.92
Permeate Alkalinity as $CaCO_3$, mg/l	240	80	30	23	38
Total Dissolved Solids Removed, %	14	76	26	24	32
Water (volume) Recovered, %	95.4	95.7	94.7	94.9	73
Filter Cake (residual waste solids) Cake pH	9.2	9.8	9.3	8.7	8.2
Dry Solids in the Filter Cake, %	12	32	30	25	26
Cake Density, gm/cc	1.13	1.37	1.23	1.21	1.25
Waste solids Generated, %* = 100 x solids vol./Wastewater vol.	4.6	4.3	5.3	5.1	27
Order of Magnitude Reduction Total Metals	2	2	4	3	3
Aluminum	2	2	3	3	4
Arsenic	1	1	1	1	2
Cadmium	2	2	2	1	2
Chromium	NC	NC	NC	NC	NC
Copper	3	4	4	4	4
Iron	4	4	4	4	4
Lead	NC	NC	NC	NC	NC
Manganese	3	3	2	2	1
Molybdenum	2	1	1	NC	1
Nickel	3	1	NC	1	NC
Zinc	3	3	3	3	4

* - By calculation
NC - Not calculated

Table C-4. Filter Cake Output from EPOC EXXPRESS.

Run no.	alkali	Solids Mass Recovered calculated	measured	solids%
1A	NaOH	279	239	11.6
1B	NaOH	340	264	13.4
2A	$Ca(OH)_2$	343	93	30.3
2B	$Ca(OH)_2$	440	87	32.9
3B	MgO	490	17	27.6
3C	MgO	230	7.5	31.4
4A	NaOH/MgO	300	13	28.4
4C	NaOH/MgO	471	81	20.8

* calculated from the volume of water treated and % solids found in filter cake.

Analyses of the filter cakes indicated that, as expected, aluminum and iron were the predominant constituents. Heavy metals were present at much lower concentrations (Table C-5). When TCLP tests were carried out on the filter cakes, the specified TCLP metals were all below regulatory limits and/or were "non-detectable".

Table C-5. Filter Cake Metal Content

Metal	Old No. 8 Seep								Richmond Portal
	Caustic		Lime		MgO		MgO/NaOH		MgO/NaOH
	1A	1B	2A	2B	3B	3C	4A	4C	5A
Aluminum	80,200	87,900	39,600	37,200	37,600	51,000	47,500	42,150	24,100
Cadmium	69	67	32	0.6	27	33	53	32	157
Copper	21,000	21,600	9,650	9,040	8,850	11,800	11,200	9,480	4,230
Iron	251,000	274,000	116,000	109,000	106,000	146,000	158,000	120,000	239,000
Lead	<90	<39	35	0.7	<19	<17	<31	<41	<66
Manganese	1,910	1,960	899	843	996	1,300	1,000	924	241
Nickel	<39	35	9	14	11	13	17	23	<14
Zinc	7,280	7,740	3,390	3,210	3,130	3,950	6,180	3,400	20,250

Appendix D

Case Studies

The information contained in the following case studies was provided by EPOC Water, Inc. and has not been subjected to EPA's QA/QC program reviewed by EPA for accuracy.

D.1 Bench Scale Treatability Testing
EPOC Testing Facility, Fresno, CA

This case study presents the treatability testing performed by EPOC and SAIC in May of 1990 using water from the Iron Mountain Mine site. The purpose of this treatability testing was to confirm the treatability of the Iron Mountain wastewaters using the EPOC system and to determine the operating conditions, treatment chemicals, and target reductions for use of the technology.

D.l.l Beaker Tests

The first phase of the treatability testing involved beaker tests to determine which precipitating agents would be appropriate to precipitate the metallic constituents of the waste. This test was performed using beakers and filtration of the resulting slurry through a vacuum filtration apparatus using a 0.45 um membrane filter. Based on the historical water characterization data of the waste streams, lime (calcium hydroxide) and caustic (sodium hydroxide) were chosen and tested as precipitating agents.

D.1.2 Single-Tube Treatability Tests

After the beak tests, treatability tests were conducted using single-tube EXXPLOW and EXXPRESS units. Each unit **used was 2.5 cm (1 in.) in** diameter and 1 meter long. EPOC chose to use only lime as a precipitating agent during these tests.

The tests were **conducted by treating the wastewater from both the** Old No. 8 seep and the Richmond Portal by precipitating with lime and heating the slurry using the two bench-scale process units. Sampling and analysis of the feed. permeate and filter cake from these units was performed for the units on both of the streams. The analytical results are summarized in Table D-l. Overall, the results show the applicability of the technology to the acid **mine drainage; a reduction of four orders of magnitude of some of the toxic metals was produced by the bench-scale technology.**

Table D-1 . Treatability Test Results

Parameter	Richmond Portal Treated with Lime		Old Number 8 Mine Seep Treated with Lime	
	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)
Aluminum	1,800	<0.45	680	<0.45
Arsenic	38	0.11	0.18	<.19
Barium	<2.0	0.105	<2.0	0.022
Beryllium	0.60	<.002	<0.16	<0.002
Boron	1.8	0.729	<1.8	0.229
Cadmium	13	<0.004	<0.34	<0.004
Calcium	250	480	110	640
Chromium, Total	<1.2	<0.015	<1.2	<0.015
Cobalt	<1.0	<0.015	<1.0	<0.015
Copper	160	0.059	140	0.027
Iron	14,000	0.057	1,800	<0.007
Lead	<3.9	<0.06	<3.9	<0.06
Magnesium	580	3.3	380	1.1
Manganese	16	<0.002	14	<0.002
Molybdenum	17	0.252	<3.2	0.237
Nickel	<1.4	<0.015	<1.4	<0.015
Potassium	230	190	<3.3	<0.050
Selenium	<24	<0.025	<24	<0.025
Silicon	88	1.89	59	<1.38
Sodium	150	130	<6.0	6.5
Thallium	<22	<0.30	<22	<0.30
Vanadium	1.6	<0.012	<0.87	<0.012
Zinc	1,800	<0.008	61	0.014
Conductivity	270,000	3,700	18,000	3300
pH	1.1	9.4	2.6	9.9
Sulfate	55,000	1,800	8,900	1,200
Total Dissolved Solids	94,000	2,900	15,000	2,700

D.2 Hazardous Waste Reduction
FMC Corporation, Fresno, California

This case study presents the use of a **combination EXXFLOW/EXXPRESS system** to remove pesticides, heavy metals and oils from a rinse liquid produced by the FMC Corporation. The system is in use for recycling of the water and for hazardous waste volume **reduction.**

D.2.1 Facility Operations

An EXXFLOW/EXXPRESS combination system is used. The waste stream, at 10 to 15 gpm. is adjusted to pH 11 prior to entering the EXXFLOW microfilter. Because of the higher pH, the hazardous materials become less soluble and are **precipitated. The EXXFLOW microfilter concentrates the hazardous constituents to twenty times the original concentration and removes the oil emulsions present in the waste. The concentrate stream is directed to the EXXPRESS unit where it is dewatered to 45% solids by the automatic tubular press. The liquid removed from the cake by the press is recycled to the EXXFLOW feed. The EXXFLOW recoveres 99%** of the water. The filtrate is polished with a small activated carbon adsorption unit prior to reuse by the plant

D.2.3 System Performance

Twenty to 50 gal/day of filter cake is produced from this unit. as compared to the 10 to 15 gal/min of influent Ninety-nine percent or better of all of the hazardous constituents are removed by the system, as shown in Table D-2. The system has been in use since 1989.

Table D-2. Removals of Hazardous Constituents

Constituent	Raw Feed Concentration (µg/L)	Filtrate Concentration (µg/L)	Concentration After Carbon (µg/L)
Organochlorine Pesticides	34,330	30.0	0.07
Organo-phosphorus Pesticides	191,360	587.3	0.30
Carbamate Pesticides	8,500	21.0	None detected
Total Pesticides	234,190	638.3	0.37
Total Metals (As, Cr, Cu, Pb, Zn)	23,143	230	--
Oil and Grease	>5,000,000	<25,000	--

D.2.3 Costs

The capital cost for this technology application was approximately $175,000; installation costs were $12,000. The volume reduction as well as the production of a semi-dry product significantly reduces the disposal costs for the operation. The ability to reuse the water in the plant provides an additional cost savings. Epoc estimates that a cost savings of $1.5 **million per year** is being achieved versus disposal of the liquids as hazardous waste. As hazardous liquids become more difficult to dispose of due to new regulations, and the cost of water increases, the use of this technology could provide substantial savings over the long term.

This case study describes the use of a combined EXXFLOW and EXXPRESS unit to treat contaminated groundwater at an abandoned manufacturing plant. The groundwater was determined to contain hexavalent chromium at 500 to 600 ppb and elevated levels of trichloroethylene. Fifty gpm of groundwater was formerly being pumped and treated with an ion exchange system for removal of the chromium, while air stripping was used to remove the trichloroethylene. EPOC estimates that substituting the EXXFLOW/EXXPRESS unit for the ion exchange significantly reduced the operating costs. The EPOC system was installed in January of 1991. See Figure D-l for a process schematic.

D.3.1 Facility Operations

A single stage chemical reactor is used to precipitate the hexavalent chromium. The precipitate3 are then removed from the water using the EXXFLOW microfilter. The EXXPRESS tubular filter press is then used to dewater the EXXFLOW reject so that kss than 1 lb/day is produced while returning the liquids to the EXXFLOW feed. The permeate from the EXXFLOW is then treated by the existing air stripper for removal of the trichlorethylene. The treatment system is interlocked with the groundwater pumps, the air stripper and a chromium analyzer for the treated water.

D.3.2 System Performance and Costs

The EXXFLOW treated water contains less than 10 ppb of total chromium, well within the regulatory limit of 50 ppb. No information on reliability is available for this system.

The cost for the equipment was approximately $150,000 and installation costs were $12,000. The operating costs for this treatment system are estimated at $0.25 per 1000 gal for electrical power (12 HP at 460 VAC) and $0.02 per gal for chemical consumption. Labor and maintenance costs were not reported. EPOC estimates that the projected payback time for their unit over the ion exchange is less than twelve months.

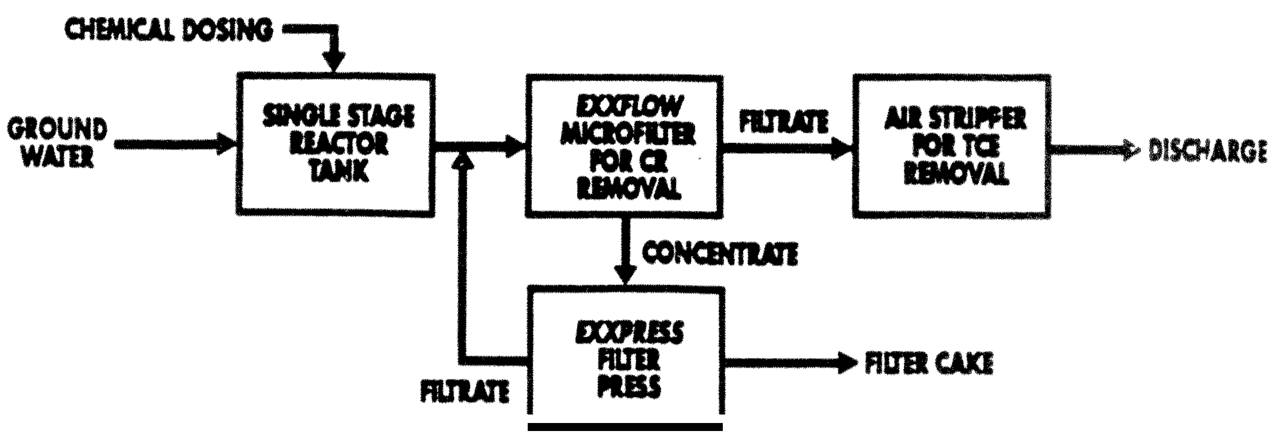


Figure D-1 Talley Corporation Process Schematic

D.4 ZeroDischarge of Ceramics Waste
Duncan Enterprises, Fresno, CA

This ceramics **factory** produces a waste stream containing up to 2 gm/l of lead and other heavy metals and 23% w/w suspended solids including ceramics fines, clays, paint **pigments,** and binders. Since the cost of disposing of this material was becoming prohibitive, recycling was investigated. The solids and metals were being removed through a rotary vacuum filter using diatomaceous earth (DE) as a filter aid.The DE added nearly 50% to the waste volume and precluded recycling of the solids.

D.4.1 Facility Operation

An EXXPRESS Automatic Tubular Press was used first in the treatment train to dewater the high solids waste. The filtrate from the EXXPRESS unit is treated to lower the pH and precipitate the remaining heavy metal constituents. The metal precipitates are removed from the liquid in an EXXFLOW microfilter having a 20 gpm capacity. The EXXFLOW produces a filtrate of high enough quality to be recycled in the plant.

The concentrate from the microfilter is added to the feed for the EXXPRESS unit. The filter cake from the EXXPRESS, containing 50% solids, is dried and vitrified for reuse as ceramic frit. AU waste in the unit is recycled so that no disposal is required.

D.4.3 System Performance

The final filtrate water quality is compared with the raw feed in Table D-3.

Table D-3. Concentration Comparison

Constituent	Raw Feed	Filtrate	Cake
Suspended Solids (g/l)	20-50	<0.01	50% w/w
Lead (mg/l)	2000-6000	<0.20	
Cadmium (mg/l)	18	<0.05	
Cobalt (mg/l)	21	<0.03	
Zinc (mg/l)	295	<0.05	

D.4.3 Costs

Epoc estimates that the unit saves over $500,000/year compared to disposal costs. The EXXFLOW/EXXPRESS unit has been in operation since May of 1990.

D.5 Industrial Waste Water
Commercial Aluminum Cookware, Toledo, OH

This case study presents the use of a combined EXXFLOW and EXXPRESS microfiltration system to remove machine oil. kerosene and particulates from process washwater. The waste stream comes from a water wash and rinse removing oil and dirt from aluminum cookware prior to a deionized rinse and hard anodizing. The water contains up to 150 mg/L of oil and grease.

D.5.1 System Operation

EXXFLOW microfiltration was chosen to treat the wastewater to recycle quality. An inert powdered absorbent is added to the water, binding to the oil and grease and allowing them to be removed by the microfilter. The microfilter also removes metal fines and other particulates present in the waste stream. Up to 40 gpm of wash water are treated by the system. The solids from the EXXFLOW filter are concentrated further in an EXXPRESS tubular filter press. The resultant filter cake has 30 to 40% w/w of solids.

D.5.2 System Performance

Use of the EXXFLOW process removes the metal fines, measured at 10 to 50 mg/L, to below detectable levels. The oil and grease content of the water is reduced from 150 mg/L to less than 5 mg/L. Since 5 mg/L is the discharge limit for oil and grease for the stream, treatment with the EXXPRESS unit would allow discharge of the effluent to the sewer system. However, the water quality of the effluent is also acceptable for reuse in the process washer and 99% of the water is now recycled in this manner.

D.5.3 Costs

While no detail cost data are available for this case study, EPOC estimates that the 40 gpm system as installed returned its total cost within the first three months of operation. as compared to off-site disposal of the contaminated water.

D.5.4 Reliability

This system was installed in July of 1990 and continues to be in operation. No other reliability information is available.

*U.S. GOVERNMENT PRINTING OFFICE: 1995-653-484